YEAR BOOK

OF THE

American Iron and Steel Institute

1914

MAY MEETING, NEW YORK

OCTOBER MEETING, BIRMINGHAM

Compiled by

JAMES T. McCLEARY

SECRETARY

Published by the

AMERICAN IRON AND STEEL INSTITUTE

30 Church Street, New York

THE TROW PRESS
NEW YORK

FOREWORD

This is the fourth Year Book of the American Iron and Steel Institute.

The first Year Book gave the proceedings of the International meeting which began in New York on Friday, October 14, 1910, and was continued in Buffalo, Chicago, Pittsburgh and Washington. In 1911 the Institute held no general meetings.

The second Year Book gave the proceedings of the two general meetings held in 1912, the May meeting in New York and the October meeting in Pittsburgh.

The third Year Book gave the proceedings of the two general meetings held in 1913, the. May meeting in New York and the October meeting in Chicago.

The present volume contains the proceedings of the two general meetings held in 1914, the May meeting in New York and the October meeting in Birmingham.

Mr. Howard H. Cook, Assistant Secretary of the Institute, rendered material aid in the compilation of this volume.

James T. McCleary,
Secretary.

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AMERICAN IRON AND STEEL INSTITUTE

SIXTH GENERAL MEETING

New York, May 22 and 23, 1914

The Sixth General Meeting of the American Iron and Steel Institute was held in New York City on Friday and Saturday, May 22 and 23, 1914.

Following the practice of the preceding meetings, three sessions were held on Friday at the Waldorf-Astoria Hotel. The forenoon and afternoon sessions, held in the Astor Gallery, were devoted entirely to the reading and discussion of papers. The evening session, including the Annual Dinner, was held in the Grand Ball Room. As usual, the papers and discussions covered questions of metallurgical science, of business, and of welfare work.

On Friday the Secretary had a temporary office near the Astor Gallery, where members registered for the meeting and were provided with identification buttons and with programs.

The paper read by Mr. Herman A. Brassert on Modern American Blast Furnace Practice had been printed in advance in pamphlet form and was distributed before the opening of the forenoon session. Dr. Darlington's paper at the evening session on The Present Scope of Welfare Work in the Iron and Steel Industry was illustrated by nearly one hundred stereopticon views part of which have been reproduced in this volume.

At the noon recess on Friday, the members of the Institute were its guests at a buffet lunch and in the evening at the banquet.

Saturday, as usual, was devoted to informal visits of places of interest in and near New York City.

The attendance was the largest in the history of the Institute, numbering nearly five hundred.

On the nest page will be found the program of the Friday sessions, at all of which the President of the Institute, Judge Gary, presided.

FORENOON SESSION, 10:00 A. M.

Address by the President.................................ELBERT H. GARY

Modern American Blast Furnace Practice...........HERMANN A. BRASSERT
Superintendent, Blast Furnaces, Illinois Steel Company, South Chicago, Ill.

Discussion...JOHN N. REESE
General Superintendent, Northern Furnaces, Republic Iron and Steel Company, Youngstown, Ohio

Discussion.......................................ARTHUR J. BOYNTON
Superintendent, Blast Furnaces, The National Tube Company, Lorain, Ohio.

Discussion.......................................RICHARD V. MCKAY
Superintendent, Blast Furnaces, Pennsylvania Steel Company, Steelton, Pa.

Discussion..EDGAR S. COOK
President, Warwick Iron and Steel Company, Pottstown, Pa.

The Importance of the Investment Factor in Sales Policy...THOMAS J. BRAY
President, Republic Iron and Steel Company, Youngstown, Ohio.

Discussion..................................C. SNELLING ROBINSON
Second Vice-President, Youngstown Sheet and Tube Company, Youngstown, Ohio.

Discussion....................................HARRY D. WESTFALL
Vice-President, LaBelle Iron Works, Steubenville, Ohio.

AFTERNOON SESSION, 2:00 P. M.

The Practical Importance of Heat Treatments in the Steel Wire Industry...JOHN F. TINSLEY
Superintendent, South Works, American Steel and Wire Company, Worcester, Mass.

Discussion...JAMES W. SMITH
Factory Manager, The Wyman & Gordon Co., Worcester, Mass.

Transportation.......................................J. FRED TOWNSEND
Traffic Manager, National Tube Company, Pittsburgh, Pa.

Discussion..DELOS W. COOKE
Vice-President and General Traffic Manager, Erie Railroad Company, New York.

Recent Progress in the Building of Large Steam Turbines..FRANCIS HODGKINSON
Engineer, Westinghouse Machine Company, East Pittsburgh, Pa.

Discussion...HENRY G. STOTT
Superintendent, Motor Power, Interborough Rapid Transit Company, New York.

Some Recent Developments in By-Product Coke Ovens..WILLIAM H. BLAUVELT
Consulting Engineer, Semet-Solvay Company, Syracuse, N. Y.

Discussion......................................CARL A. MEISSNER
Chairman, Coke Committee, United States Steel Corporation, New York.

EVENING SESSION, 7:00 P. M.

ANNUAL DINNER

Present Scope of Welfare Work in the Iron and Steel Industry.............................THOMAS DARLINGTON, M. D.
Secretary, Welfare Committee, American Iron and Steel Institute, New York.

Discussion...............................SIDNEY MCCURDY, M. D.
Chief Surgeon, Youngstown Sheet and Tube Company, Youngstown, Ohio.

Impromptu Remarks in response to call of Judge Gary

Remarks by the President.............................ELBERT H. GARY

ADDRESS OF THE PRESIDENT

ELBERT H. GARY

Chairman, United States Steel Corporation, New York

Again it is my pleasure and honor to welcome to our annual meeting the members of this Institute. The meeting promises to be notable, not only for the very large attendance but also for the literary and scientific papers which will be offered. When you consider the number of the members and the work which is being done and the benefits which we are deriving from our association, I think we may say it is worth our while to belong to the Institute and to present ourselves at the meetings. Our membership now is over twelve hundred, and it is increasing. It seems that this Institute promises to be one of the most influential organizations in this country and perhaps of any other single country. That you are cordially supporting the Institute entitles you to expressions of gratification from the officers, and in fact from everyone who is interested in it.

The papers which will be read during the day will, in many respects, be extraordinary, and they will be valuable; and I think I am justified in saying to those who are contributing, that they will receive due reward for devoting so much time and attention to the preparation and the presentation of these papers. They are making a record of their work which will be enduring and to which they and those who come after them may point with pride and satisfaction.

THE TEMPTATIONS OF HARD TIMES.

In times of prosperity it is very easy for us to be generous in our treatment of all the questions which are presented to us for consideration and determination. In such times it is not difficult for us to be generous to our employees and towards one another. If our mills are running at full capacity and our earnings large, and our balances in the

bank entirely satisfactory, it is natural for us to pay large wages and to deal kindly towards each other, avoiding doing anything that is unfair, giving every opportunity to inspect our mills and to know what we are doing to secure the greatest economies, and, in fact, to permit each other to know the names of our customers and even the bookings which we have; and there have been times when this generosity has been shown in a marked degree by those who are connected with this great industry. But when the orders on our books are small and the prices are low, and the demand much below capacity to supply, we are all more or less inclined to be selfish. Possibly some of us are forced to do everything we can to secure orders and to take care of our own interests, regardless of the rights and interests of our competitors in business, and also, sometimes, without regard to our obligations to our employees.

Six Months Nearer the Dawn.

Without intending to emphasize the conditions which obtain at the present time, I would be less than frank and truthful if I failed to admit that business is not as good as we would like to have it. I would like to say just what is in my mind concerning this subject, but perhaps it is unnecessary. I said six months ago, at our semi-annual meeting, that, in my opinion, we were approaching the dawn of prosperity. Well, gentlemen, don't forget that we are six months nearer the dawn. (Applause and laughter.)

But in times like these, I ask you to consider not only the propriety, but more than that, the pleasure of being fair, reasonable and generous in our treatment of our employes and our treatment of one another. It is not necessary at this time to speak of being generous to our customers, for they are taking care of themselves. (Laughter.) But it is necessary to be very considerate of each other, and it is not only our duty, as members of a fraternity who have established a reputation for fair and honorable dealing, to be very careful not to do anything that is unjust towards each other, but it pays in dollars

and cents to occupy and to pursue that course. There is no one man or company so capable, intellectually or otherwise, that he or it can afford to ignore the rights of others.

I am dealing in generalities and without any intention to refer to any individual or any company. We are all on the same basis. We are all trying to take care of ourselves but we should all, at the same time, have a disposition to try and help one another.

Some Favorable Indications.

There are some favorable things to be considered. In the first place, as is our habit, we point to the crops of the year. They are something that cannot be taken away from us, even by the politicians. The crops are growing. We are going to have an abundance this year, and they will have their influence on the business conditions of this country. We shall see improvement. This country is just as big as it ever was; it is growing just as fast. It is rich, and it is bound to be prosperous. Depressions are temporary. If we are careful of our business, if we husband our resources, if we have patience, courage, persistence, we will come out in the end all right.

But there is another thing I believe more important. As I read the signs of the day, there is a well developed sentiment throughout this country in favor of giving business—even big business—a fair chance. (Applause.)

Hereafter the statesman occupying or accepting candidacy for political office will be popular if he has the disposition and the courage to insist that there can be no contentment or acquiesence on the part of the masses of the people unless they believe everything reasonable is being done to promote and maintain material growth and prosperity. The people will not listen patiently to discourses in favor of moral uplift unless at the same time the necessities of life are provided. (Applause.)

The President: You are all supplied with programs giving the order of the papers and discussions and the

authors thereof. The program also shows the position occupied by each of these gentlemen, thus indicating his competency to speak on the subject. In order to save time, the Chair will ask each of the authors in succession to come forward to the platform and read his paper without further introduction.

MODERN AMERICAN BLAST FURNACE PRACTICE

HERMANN A. BRASSERT

Superintendent of Blast Furnaces, Illinois Steel Company, South Chicago, Ill.

The trend of development in the manufacture of pig iron is much the same the world over. With more and more difficult raw materials, progress is not so much in the direction of new records of production and fuel consumption, as in the ability to maintain the best results of the past in the face of greater handicaps. Since this paper cannot cover all conditions of raw materials and every kind of practice, I will confine myself largely to the foremost problems which the present generation of blast furnace men has been called upon to meet—the smelting of fine ores. It is hoped that this may assist in opening up a field for a wider discussion in detail of the many modes of construction and operation which form so important a part in modern furnace practice.

The present state of the blast furnace art is as much the result of practical experience and common sense as it is of science; however, the underlying principles of the process must be understood in order to appreciate its possibilities, as well as its limitations. I will, therefore, give a brief outline of the theory of the blast furnace process, and then discuss the possibilities and means of obtaining better economy, dealing first with the raw materials, next with the construction, and finally, with the operation of the furnace.

The blast furnace process for the production of pig iron is an invention of the Middle Ages. It was practiced in Germany in a primitive manner as early as the beginning of the 13th century. The first American blast furnace was built in 1644 on the shores of Massachusetts Bay. A tremendous development has taken place in the practical application since the early days, but the process, in prin-

ciple, has remained the same. The reason for its survival to the present day lies in its economy. It always has been, and is today, the most efficient of all metallurgical processes.

THEORY OF THE PROCESS.

The blast furnace performs the task of preheating the ores, reducing their metallic contents, and melting the resulting iron and slag, in one continuous process, and in the same vertical stack. The counter-current principle is employed, whereby raw materials and gases travel in opposite directions, the heat of the latter being transmitted gradually to the former, with the result that the waste gases leave the process at the point of lowest temperature, whereas the materials to be melted enter the zone of fusion highly preheated.

By the concentration of heat in a comparatively small area in the lower part of the furnace, radiation losses are small as compared to other metallurgical furnaces. Being practically constant per unit of time, for a given furnace, they decrease almost in proportion to increased output, and under modern conditions are kept well below 10 per cent. of the total heat involved. The loss of sensible heat in the waste gases is decreased to a minimum by the continuous transmission of heat from the gases to the descending stock.

Direct and Indirect Reduction.

Simultaneously with this transfer of heat from gases to raw materials, and in the same manner, the reduction of the oxides takes place. The descending ores are gradually reduced by the carbon monoxide of the rising gases, the leanest gases coming in contact with the highest oxides at low temperatures near the top, the richest gases meeting the ores in their final stage of reduction near the melting zone. Thus the largest possible proportion of the iron oxides is converted into metallic iron in the most economical way, for the reduction by carbon monoxide of Fe_2O_3 is a slightly exothermic reaction, and that of FeO, while being endothermic, requires only a small amount of heat. The

"direct" reduction by solid carbon, on the other hand, which must be applied to such portions of the iron oxides as have escaped the "indirect" reduction, is much more extravagant, requiring five or six times more heat than the reduction by the gases.

Since iron oxides are reduced by the gases in the blast furnace only within a certain range of temperature, lying between 200° and 1100° C., and since it is difficult for the gases to reach every particle in a big bulk of ore in time for proper preheating and reduction, it will be at once understood that the furnace charge must descend regularly and the contact between gases and stock must be both intimate and uniform, in order to facilitate the "indirect" reduction by the gases.

These fundamental principles have always been the same, yet there exists quite a variation in the efficiency of different furnaces in actual practice, even when working under the same conditions. An efficiently operated furnace is delicately balanced and is easily influenced by irregularities of any kind. Slight changes of temperature disturb the equilibrium between "direct" and "indirect" reduction. An increase of direct reduction consumes additional carbon which otherwise would have been available for combustion at the tuyeres, there to generate heat for the melting process, and this fuel must be replaced by charging more coke at the top. The reduction by solid carbon consumes also more heat than that by CO, which again has to be replaced by adding more fuel. The larger the ratio of coke to ore in the charge the greater the quantity of top gases per ton of iron, and the higher their temperature and calorific value, resulting in further loss of heat to the furnace.

Increased top temperature shortens the zone of possible reduction by CO, since CO_2, which is the product of this reaction, cannot exist at high temperatures in contact with carbon. Under such conditions any CO_2 formed in the reduction of ore or calcination of limestone immediately reacts with carbon, forming CO and resulting in lowering the ratio of CO_2 to CO in the gases, and in a further loss of carbon to the generation of heat at the tuyeres. This ex-

plains why such a large excess of fuel is generally required to bring a cold furnace back to a normal condition.

The top temperature, therefore, in conjunction with the ratio of CO_2 to CO in the escaping gases, is a true indicator of blast furnace economy. The higher this ratio, the more efficient the reduction process. Low top temperatures go hand in hand with high $CO_2 : CO$ ratios, and high top temperatures with low ratios.

Successful Practice.

The success of a blast furnace operation is measured by three results—quality of product; rate of output; and economy of operation. The first step towards their attainment is the realization that they can be accomplished by identically the same practice, the keynote of which is uniformity and heat concentration. If a blast furnace man strives for a uniform operation, giving the highest production combined with the lowest fuel consumption, he will also obtain the best grade of iron. The incessant struggle for uniformity should embrace not only the raw materials, but their distribution and descent in the furnace, brought about by proper plant design and furnace lines, as well as by intelligent operation. Such efforts will result in maintaining the largest possible proportion of "indirect" reduction, which allows the maximum amount of the carbon charge to be burnt at the tuyeres, and gives the highest hearth temperature, which means the best grade of iron. The escaping top gases will then have the lowest temperature and the highest ratio of CO_2 to CO, and will approach the ultimate economical limit, which is reached when the $CO_2 : CO$ ratio becomes so "high"—i.e., the gases so lean—that they have lost their reducing power; or when the top temperature has been decreased to a point where the ores are not properly preheated for the reduction and melting process. This limit is determined by the reducibility of the ores. How closely it can be approached in practice on various grades of iron depends on furnace construction, mode of operation, and their proper adaptation to the raw materials.

RAW MATERIALS.

Ore.

In most countries the manufacture of iron starts with the best ores, rich in iron, and of a favorable physical structure. Such conditions facilitate good furnace operation and favor low fuel consumption, but they also tend to retard progress. In modern times, and in all civilized countries, the supply of high grade ores has been greatly reduced, compelling the use of materials leaner in metallic content and of adverse physical character, which render good blast furnace practice much more difficult. This, however, stimulates improvement, and today ores are economically smelted which were formerly discarded. In fact, thanks to improved furnace construction, a general change in opinion as to the most desirable materials is taking place; and while formerly coarseness was considered an indispensable quality, we now object to large lumps and prefer granular ores, as they allow the closest contact between their metallic contents and the furnace gases, and therefore can be reduced with a minimum expenditure of fuel.

Very fine ores are undesirable because too large a portion is carried over with the gases, increasing the loss. They also make the stock column too dense and induce channeling of gases, with the result that part of the ores are not properly prepared before reaching the melting zone, and part of the gases reach the top of the furnace without having fully exerted their reducing power or given off their sensible heat. Fine materials also tend to adhere to the walls of the furnace, and result in scaffolding, hanging, and slipping—symptoms familar to every furnace man who has used Mesaba ores.

These conditions are sometimes aggravated by the dissociation of CO, induced by the presence of finely divided oxides of iron in the upper part of the furnace. The result of this reaction is a deposit of fine carbon upon the ore charges, causing them to swell and increasing the tendency of the furnace to hang.

Too much importance, though, has been given to this

phenomenon, especially in foreign literature. We have sufficient proof that is does not take place, to any marked extent, in a normally driving furnace. In Lake ore practice, the color of the gases escaping from the furnace top during slips is a clear, reddish brown; black smoke, showing the presence of finely divided carbon, issues only after protracted periods of hanging. Furnaces using the highest percentages of Mesaba ores will run along for many months without ever showing any sign of carbon deposition, so that this reaction evidently has no bearing on the economy of the process.

Fine ores can be worked to the best advantage when they are delivered to the furnace in a state of physical and chemical uniformity. The United States Steel Corporation has made wonderful strides in this respect by developing a system of mining, sampling, grading and mixing of its ores, which has resulted in a remarkable uniformity of the various shipping grades. This is the more admirable considering the great variation of the physical and chemical character of the ores contained in the same mine.

As an example of the fineness of burdens carried at the present day, the following is a table giving the results of sieve tests on all the ores shipped to the South Works of the Illinois Steel Company during the season of 1913:

Ores	Per cent. on Screen								Through No. 100
	%	No. 2	No. 8	No. 20	No. 40	No. 60	No. 80	No. 100	
Mesaba..........	83.3	25.40	26.86	12.54	10.86	6.92	2.76	3.34	11.33
Old Range.......	16.7	30.16	30.76	15.01	8.14	4.16	2.06	2.74	7.01
Total........	100.0	26.10	27.58	12.93	10.51	6.44	2.56	3.23	10.69

The suitability of any iron bearing material for blast furnace use depends on its physical form as well as on its degree of oxidation. Large lumps, even of easily reducible ores, are objectionable, because they reach the melting zone improperly preheated and reduced only on the surface. The same materials, which, if charged in the form of lumps, cool

off the hearth, can be used to good advantage if properly crushed.

With increasing fineness of the ores, on the other hand, it appears more and more desirable to render the burden more open by preliminary treatment of the finest materials. Considerable is already being done in this regard by sintering and nodulizing the ores, and much will undoubtedly be accomplished in the future. By the addition of such pre-treated materials the physical character of the entire charge can be greatly improved. The first step in this direction is to treat the flue dust instead of recharging it in the raw state.

Briquettes of flue dust and ore are made on a large scale in Europe by a number of well known processes. In this country their introduction has been slow. The difficulty is to make them sufficiently strong, yet not too dense, and without introducing undesirable elements as binder.

Sintering, by the down-draft process, and nodulizing in a rotary kiln are practiced to excellent advantage on flue dust. They give a product of considerable physical strength and great porosity, which is easy to reduce if agglomerated without melting. A rotary kiln, treating about half of the flue dust produced, has been in operation at the South Works of the Illinois Steel Company for the past eight years. Its nodules of uniform size, rich in iron, and pre-reduced in the kiln without being melted, have proved beneficial to the furnaces even when running on the lowest coke consumption.

As the ores become leaner in metallic contents, the gangue gradually increases, until it may become an economical necessity in order to save transportation charges, to locate the furnace plant nearer the ore deposits, or by treatment of the ores, to eliminate part of the gangue, which will also serve to reduce the cost of smelting.

Ores high in alumina have previously been considered very undesirable, if not prohibitive, for blast furnace use on account of the generally experienced decrease in fluidity of slags with increase in alumina contents. One of the most important of recent developments in American blast furnace

practice is the commercial use of Cuban ores, very high in alumina.

Highly silicious ores, on the other hand, will never be suited for direct smelting except in mixture with self-fluxing ores, on account of the excessive amount of limestone required to flux the silica. The silica content affects the economy of the melting process at an increasing rate, as soon as it exceeds the amount necessary to form the desired slag volume. The elimination of silicious gangue, clay, gravel, or sand by washing is conducted on an extensive scale on the Mesaba range, the largest plant being operated by the United States Steel Corporation at Coleraine, with a daily capacity of from 30,000 to 35,000 tons of washed ore. By this operation ores with 45 per cent. iron content are enriched to 56 per cent. of iron, and at the same time a silica content of 30 per cent. is reduced to 10 per cent. and less.

Another field of great promise for the future lies in the concentration of titaniferous magnetites and in their successful use in the blast furnace. It is quite possible, and the latest results seem to indicate, that slags high in TiO_2, if uniform, will offer no more serious obstacles than those high in alumina, not to mention the possible advantage of the titanium content in pig iron for foundry or other special grades.

The commercial possibility of the reclamation of ores by washing, drying, magnetic concentration, sintering and roasting, must always depend on their physical and chemical character, on the cost of power, mining and transportation, and sometimes on the value of tailings as a by-product.

Whether the ores are used in their natural state or after preparatory treatment—which in the case of concentration always involves a loss of metallic contents in the tailings—the maximum possible yield of iron from any deposit is determined by the percentage of metallic contents in the ore; and this yield would be attained by their complete conversion into pig iron without any loss in flue dust and slag. The loss of iron in the slag is a comparatively small item, and quite uniform everywhere. The downcomer loss, while showing a greater variation, can be recovered by

treating the fine dust and re-charging it into the blast furnace. Thus it is seen that the consumption of ore per ton of iron in the blast furnace is largely fixed by nature.

COKE.

The consumption of coke, on the other hand, which is an artificial product, is subject to much greater variations, and depends to a far greater extent on human skill. To manufacture a coke of the most desirable quality and to develop the most suitable furnace lines, are today the two foremost tasks in striving for better furnace economy.

The fuels given us by nature are poorly suited for the blast furnace. In remote times wood was used. In order to obtain greater calorific intensity, this was later converted into charcoal, which, being chemically very pure, was particularly suited to the production of low sulphur iron. Rapid deforestation, however, compelled the introduction of coal as a blast furnace fuel as early as the beginning of the 18th century. The scarcity of proper coals, and the tendency, even of the anthracites, to crush and crumble in the furnace charge, led to the coking of the coal. The resulting artificial product was soon found to be superior, and rapidly replaced the use of even the best anthracites.

The coking process was at first conducted in bee-hive ovens. While capable of producing a coke of satisfactory quality, the bee-hive process is very uneconomical, on account of wasting the coke oven gases and their valuable by-products as well as part of the fixed carbon of the coal charge. Its lack of economy and its limitations to certain grades of coal led to the development of the modern by-product oven, which affords the possibility of using a greater variety of coking coals; and owing to the recovery of the by-products and the higher yield, permits the assembly of coals at the ovens, there to be mixed in proper proportions for the purpose of manufacturing a uniform and suitable blast furnace coke.

In the by-product oven a satisfactory coke can be made from coals which cannot be coked to advantage in beehive ovens, and enormous coal fields have become available for

the manufacture of metallurgical coke, largely adding to the national wealth.

Bee-hive ovens, on account of their low yield, are naturally located at the coal mine, necessitating the use of only one kind of coal, and making a product which is subject to all the variations of the coal from this particular mine. Furthermore, due to the limited supply of coal from a single mine, a bee-hive operation generally does not produce sufficient coke to supply a large blast furnace plant, so that often a number of different cokes have to be used on a furnace and the uniformity of this mixture is very difficult to control.

The by-product process is more flexible in the coking operation and is capable of improving the quality of the coke by variations of temperature and coking time to an extent unknown and impossible in bee-hive practice. By locating the by-product ovens at the blast furnace and making them a part of the furnace or steel plant, the daily co-operation of manufacturer and consumer insures the best possible furnace results.

A hard metallic structure has always been considered the first requisite of a good furnace coke, indicating its ability to resist abrasion. The crushing effect of the charges by weight is comparatively small, and the average furnace coke has many times the required strength. But the abrasive treatment to which the coke is subjected in the handling, and more so in the furnace where it is simultaneously attacked by the gases, is severe; and unless the coke is hard but not too brittle, and tough without being soft, it will go to pieces on its downward path in the furnace.

While fine, soft ores in the burden protect the coke against abrasion, the presence with such ores of coke breeze and dust is particularly detrimental by further increasing the density of the stock column and by accumulating on the walls, causing scaffolds to form. The heat value of coke dust to the furnace is practically nil, since that portion which is not blown over into the dust catcher is consumed in "direct" reduction with the ores and by the CO_2 in the gases, so that it has but little chance of ever reaching the tuyeres.

The effect of size on the vulnerability of the coke to dissolution by CO_2 is shown by the following laboratory tests, which were made at the South Works to determine the loss in weight of various kinds of coke on treatment with dry CO_2 at different temperatures:

PERCENT. LOSS IN WEIGHT AFTER BEING TREATED WITH CO_2 FOR TWO HOURS

Kind of Coke	Samples Crushed to Pass Through ½ in. and Remaining on ¼ in. Mesh at				Samples Crushed to Pass Through 80-Mesh at			
	800°C.	900°C.	1000°C.	1100°C.	800°C.	900°C.	1000°C.	1100°C.
Connellsville	.25	.19	1.97	4.38	.20	5.00	9.70	52.80
Klondike	.45	.84	2.90	6.50	.50	4.55	16.27	46.33
By-Product:								
No. 1	.50	1.34	4.92	10.26	.80	5.45	15.75	40.98
No. 2	.25	.87	3.68	9.46	.45	3.15	17.40	51.18
No. 3	.40	.70	3.00	10.10	.50	4.20	13.00	64.60
No. 4	.25	.83	6.10	10.14	.80	3.35	16.65	47.02

These results give an idea of the extent of the destruction of fine coke by CO_2 in the upper part of the furnace, and show the futility of charging breeze and dust into the stack with the expectation of obtaining heat value therefrom. The presence of large percentages of coke dust brings with it another disadvantage, in that it vitiates the composition of the flue dust and renders it more difficult to treat. Blast furnace coke should, therefore, be thoroughly screened at the ovens or in the furnace bins, preferably in both places, in order to obtain the cleanest possible fuel.

Careful screening is also beneficial in that it lowers the ash contents of the coke, and sometimes the sulphur, as illustrated by the following ash determinations of coke fines:

Screenings	By-Product No. 1 Ash	By-Product No. 2 Ash	By-Product No. 3 Ash
On ¼-in. sieve	15.28	27.05	15.74
On No. 20 sieve	18.66	23.30	16.10
On No. 40 sieve	17.11	17.80	14.00
Through No. 40 sieve	17.28	19.71	15.00
Average of Coke	9.20	11.35	10.13

Until recent years the detrimental influence of high ash was not seriously felt in this country; therefore the washing of coals so common in Europe is still an exception here. But with leaner ores and increased cinder volume, the duty of fluxing an excess of coke ash begins to seriously increase the cost of smelting. In Lake ore practice, with 7 per cent. silica in the ores, pure stone and low fuel consumption, an ash content up to 10 or 11 per cent. in the coke represents a slag volume which is not detrimental to good practice. An excess of ash in the coke results in a threefold loss, in the shape of wasted expenditure for transportation, additional flux, and the loss of efficiency through its taking up space and heat in the furnace which should have been applied to an equivalent amount of ore.

Even more objectionable than ash is sulphur, if it exceeds a certain limit, determined by the composition, temperature and volume of the slag. These in turn are either fixed by the raw materials, or chosen to produce a certain grade of iron. To eliminate sulphur as ordinarily present, it must be dissolved in the slag, which for a given composition and hearth temperature, has a fixed saturation point, and can take care of only a limited amount of this element. In Mesaba ore practice a sulphur content of over one per cent. in the coke is very objectionable, considering the prevailing cinder volumes and the inability to obtain uniform furnace operation on very basic slags.

The problem of reducing ash and sulphur in our coking coals by dry methods or by washing opens up a wide field for profitable labor.

By-product coke should be properly quenched without any excess of water. Over-quenching spoils the surface, injures the structure and fractures the coke. When the coke is charged into the furnace by weight, a low moisture content is important also in confining the variations to a smaller range.

The physical standard by which blast furnace coke is generally measured, besides hardness and resistance to abrasion, is its porosity. It has been recognized that an open cell structure favors rapid combustion whereas a dense

structure retards it. Since the speed of combustion primarily affects the furnace practice, it appears that the combustibility of cokes should be considered a foremost quality.

The importance of the combustibility of cokes was first brought to my attention in 1906, through the use of bee-hive Pocahontas coke on the large furnaces at the South Works of the Illinois Steel Company. In appearance and structure it differed from the Connellsville and Klondike grades, but the porosity tests scarcely revealed the great difference in the action of these cokes in the furnace. A furnace which on Connellsville or Klondike coke worked normally, would on Pocahontas drive at an excessive speed. The blast pressure would drop several pounds, and the hearth would become cold, necessitating a decrease of the tuyere area and wind volume, and a lightening of the burden.

The extreme softness of the coke evidently made it highly vulnerable to dissolution by CO_2 in the furnace stack. This and excessive abrasion reduced it to small size, favoring "direct" reduction, which accelerates the movement of the stock, and not sufficient coke reached the tuyeres to maintain the temperature of the hearth. On the small furnaces at the Union and Milwaukee Works this coke, for apparent reasons, gave better results.

At this time I made a series of combustion tests with these cokes, which showed vast differences in the time required for the complete combustion of a fixed amount of coke with natural draft under equal conditions. The time required for complete combustion of the bee-hive Pocahontas coke amounted to only 47.7 per cent. of the time required to burn the same weight of Connellsville or Klondike.

With these results at hand we experimented in the following years with different mixtures of these cokes, in order to arrive at the degree of combustibility which would produce the best results in conjunction with our ore mixtures and furnace lines. In this manner bee-hive Pocahontas coke was successfully used in mixture with hard cokes. The best proportions proved to be two-third hard and one-third soft coke, as illustrated by the performance of No. 6 blast

furnace at the South Works, which from January 3rd, 1909, to December 18th, 1910, on this mixture, produced 307,517 tons of basic iron, with an average fuel consumption of 1,969 pounds of coke per ton of iron.

The early coke produced in our by-product ovens, even from the same coals, burned too slowly and made our furnace operations exceedingly difficult by preventing rapid and continuous movement of the stock. Observing the action through the tuyere glasses would reveal each piece of such coke moving slowly and requiring considerable time before being entirely consumed, whereas coke of proper combustibility dances lively at the tuyeres and quickly disappears. With fast-burning coke, each molecule of oxygen in the air immediately finds its molecule of carbon in the tuyere zone, and the combustion takes place rapidly and with great intensity. By thus concentrating the combustion in a comparatively small area, the highest heat effect is obtained. With slow-burning coke, on the other hand, the molecules of oxygen are not all able to combine immediately with their molecules of carbon. The result is that the combustion is carried higher up in the furnace, the heat generated by combustion is spread over a larger area, and the top temperature increases. The coke pieces being consumed but slowly, no rapid shrinkage of the stock takes place, such as characterizes a fast driving furnace with a highly heated combustion zone. Consequently the blast pressure goes up, the furnace begins to hang, and good practice becomes impossible.

On small furnaces such slow burning coke interferes even more seriously with the practice than on large furnaces, because the wind volume and pressure cannot be sufficiently increased to accelerate the combustion. The extremely poor results with some by-product coke led to the breaking of the larger coke pieces, with the object of increasing the active surface of the coke charge and improving the combustion particularly for the use on smaller stacks. While better results were obtained in this manner, the proper remedy is the manufacture of a coke with suitable and uniform combustibility.

This is achieved not only by using the proper coal mix-

ture and coking time, but primarily by careful heat distribution in the oven, avoiding overcoking part of the coal charge, which destroys the combustibility, and undercoking of other parts, which makes a product too soft and solvent in CO_2. The coking must be finished simultaneously at all parts of the cake of coal, which at that moment must be pushed and quenched without delay.

The following laboratory tests illustrate that by-product coke can be made of even greater combustibility than standard Connellsville bee-hive coke:

Kind of Coke	Comparative Loss of Various Cokes on Ignition in a Limited Current of Air							
	Loss in Weight at							
	300°C.	400°C.	500°C.	600°C.	700°C.	800°C.	900°C.	1060°C.
By-Product:								
No. 1.........	.20	.20	.79	13.55	15.35	14.90	15.95	19.80
No. 2.........	.64	.59	6.23	14.50	15.75	15.72	16.80	22.48
No. 3.........	.62	.47	4.18	14.55	15.70	15.60	16.20	22.60
Kentucky Bee-hive..........	.46	.78	3.90	13.40	15.80	14.35	15.40	20.75
Connellsville Bee-hive..........	.15	.15	.58	9.15	13.70	13.25	14.10	17.00

The lack of knowledge and experience along these lines was responsible for the slow progress attending the introduction of by-product ovens in this country. The product at first met with a good deal of opposition. Grades of coal similar to those which made a good coke in bee-hive ovens were used, and the coke obtained was too dense and gave very discouraging results, especially when used with Mesaba ores. Good blast furnace practice was not accomplished until such coals were substituted which, in bee-hive ovens, had made a coke too soft for blast furnace use. By modifying the oven operations in regard to heat regulation and coking time, the by-product coking process has made rapid strides in recent years, and to-day at a number of American plants by-product coke is made which rivals in quality our best bee-hive product.

As a practical proof of what has been accomplished in perfecting the quality and uniformity of by-product coke, the results obtained on the blast furnaces at the South Works with coke from the Gary and Joliet ovens, are of interest. The coke is made with a coking time of from 16 to 18 hours using 60 per cent. and over of low volatile Pocahontas coal in a mixture with various high volatile coals. The South Works furnaces, by their average coke consumption of 1,944 lbs. during the past twelve months, have established a yearly fuel record for any group of furnaces using a similar grade of ores. Monthly figures from May 1st, 1913, to May 1st, 1914, by stacks, were as shown in the table on page 31.

LIMESTONE.

As the economical smelting of the finer and leaner ores of modern times requires special care in the manufacture of coke in order to obtain the best furnace practice, so also should we carefully prepare the flux and adapt it to the fineness of the ores and their increasing silica content.

The ore charges themselves have become so dense that any further additions of fines with the limestone are detrimental, and these should be eliminated by screening. At the same time, big lumps of stone are also more objectionable than formerly, because with the fast driving of a modern furnace they have not time to become properly preheated and reduced before they reach the melting zone. Lumps of raw lime usually make their appearance at the tuyeres when large stone has been charged. Stone for blast furnace use should, therefore, be crushed. Some stones are harder to reduce than others and should be broken relatively smaller. The fines should be eliminated by thorough screening.

Formerly, when the silica in the ores was so low that the cinder volume without the addition of special silicious materials was below the practical limit, a limestone containing 5 per cent. or 6 per cent. of silica was not objectionable. More silica in the limestone simply meant that less of these cheap materials could be used; but, providing it was uniform, it did not seriously affect the furnace practice. To-

ILLINOIS STEEL COMPANY, SOUTH WORKS

Average Daily Production and Coke Consumption per Ton
May, 1913, to April, 1914, inclusive

Month	Bessemer Pig Iron											
	No. 2 Furnace		No. 3 Furnace		No. 4 Furnace		"E" Furnace		No. 9 Furnace		Total Bessemer	
	Tons	Lbs. Coke	Tons	Lbs. Coke	Tons	Lbs. Coke	Tons	Lbs. Coke	Tons	Lbs. Coke	Tons	Lbs. Coke
May, 1913	543	1942	491	2179			565	1941	511	1963	528	2001
June	528	1974	411	2209	Blown out		570	1916	502	1958	503	2002
July	541	1912	408	2365	4–15–13		455	2087	468	1926	467	2057
August	515	1886	496	2006	Tonnage:		521	1912	469	1991	500	1947
September	508	1898	523	1890	723, 237		525	1691	516	1837	518	1828
October	496	1936	514	1964			514	1711	530	1849	514	1865
November	473	1946	528	1937	Blown in		467	1783	437	2144	477	1949
December			502	1932	2–15–14		536	1705	513	1798	515	1822
January, 1914	Blown out		474	1958			463†	1821			469	1903
February	11–23–13		479	2044	290	2464	489	1950	Blown out		445	2058
March			487	2061	518	1744	559	1815	12–18–13		521	1868
April	...	....	507	1991	543	1702	540	1845	...	....	528	1842
Average	517	1927	484	2023	485	1806	518	1851	492	1936	501	1927
Tons made on Lining	475,442		788,512		36,414		417,117		593,007			

Month	Basic Pig Iron											
	No. 5 Furnace		No. 6 Furnace		No. 7 Furnace (Basic)		No. 8 Furnace		No. 10 Furnace		Total Basic	
May, 1913	487	2159	422	1960	570	1828	467	2039	484	1926	486	1977
June	491	2195	413	1991	516	2077	439	2052	505	1893	473	2043
July	437	2177	396	2010	419	2103	506	1900	491	1923	450	2016
August	397	2351	433	1958	546	1987	482	1872	478	1962	477	1876
September			468	1873	530	1963	529	1792	500	1942	503	1893
October	Blown out		451	2007	531	1910	519	1840			500	1915
November	8–25–13		389	2016	572	1903	527	1894	Blown out		496	1929
December	Blown in		522	1654	582	1877	532	1886	10–1–13		551	1871
January, 1914	2–6–14				419‡	1986	536	1938			482	1958
February	402	2110	Blown out		529	2022	506	2029			484	2046
March	529	1882	12–4–13		532	2042	534	1888			532	1937
April	520	1910	...	....	567	1870	537	1904	...	....	542	1894
Average	476	2079	426	1969	526	1960	510	1915	492	1929	493	1961
Tons made on Lining	41,252		247,572		279,639		223,175		205,698			

Note.—No. 1 Furnace on special grades.
† "E" Furnace banked, Dec. 24, 1913, to Jan. 10, 1914.
‡ No. 7 Furnace banked, Dec. 24, 1913, to Jan. 10, 1914.

day, however, the natural silica in the ores has generally increased the slag volume to a point where it exceeds that required for carrying off the sulphur and insuring regular furnace operation. A reduction in the silica of the limestone represents, therefore, a direct saving in coke. It will also be found that the lower the silica content of a stone, the

more uniform it will be, which, of course, is a factor of the great importance.

While a moderate magnesia content in the slag is not objectionable, the use of dolomite is injurious to good furnace practice with Lake ores, where the slags are fairly high in alumina and where a low zone of fusion must be maintained. To eliminate the sulphur it has been found necessary in our practice to run on a more basic slag when using dolomite, which makes uniform furnace operations more difficult and results in a higher fuel consumption. With slags very low or very high in alumina, the use of dolomite has been found beneficial, as also in the manufacture of spiegel and ferro-manganese.

AIR.

Of all the elements introduced into the blast furnace in a given unit of time, air is the largest both by volume and by weight. It is therefore not surprising that great efforts were made towards its improvement. The cold blast of the early days was replaced in the beginning of the last century by the hot blast. With the iron pipe stoves first used, only moderate heats could be carried. Some fifty years ago firebrick stoves took their place, which allowed the blast temperatures to be increased to those of the present day. The introduction of hot blast marks the greatest step ever taken in improving the economy of the blast furnace. By the use of hot blast, combustion is accelerated, intensified and confined to a smaller space, the melting zone is concentrated, and the hearth assumes a higher temperature. The grade of iron becoming richer, demands more burden of ore to the charge of coke. This decreases the amount of gas per ton of iron and in turn reduces the top temperature, again saving heat and making possible a more economical reduction. It also causes less carbon to be consumed by CO_2 in the upper part of the furnace, whereby more is made available for combustion at the tuyeres. These effects being cumulative, the application of hot blast resulted in a far greater fuel saving than was expected from the mere addi-

tion of the heat units contained in the blast; and hand in hand with it went a large increase in production.

Another more recent method of obtaining fuel economy is the Gayley Dry Blast. The effect of this is the same as that of an equivalent increase in blast temperature. In addition it gives to the furnace a uniform supply of oxygen by weight. To this uniformity is attributed the extraordinary saving, particularly in localities with moist and variable climates, which in some cases was found to be greater than that corresponding to an equivalent increase in blast temperature.

Its applicability depends on local conditions, influencing the comparative cost of drying the air as compared with raising its temperature, and on the degree of existing furnace efficiency. At plants where a further increase of blast temperatures is not profitable because the limit of heat concentration is already reached, the dry blast will also fail to be economical except in the effect of its uniformity, which in natural air practice can only be approached by the most careful regulation of blast heats and of the weight of air blown.

The latest effort to improve the air, by the enrichment with oxygen, is being made in Europe, whether with profit or not remains to be seen. Since the ratio of CO_2 to CO cannot be increased above the point where the gas loses its reducing power, and this point remains the same whether or not it is diluted with nitrogen, and since this limit, as well as that of lowest top temperature, can be approached by the employment of less expensive means, it is at least doubtful if the oxygen method will ever come into general commercial use. The uniform heating of the furnace charges to the melting point requires time and a certain volume of gases, and these apparently cannot be decreased, even if it should be possible to shorten the reduction period by lowering the inert nitrogen content of the gas.

The hot blast and dry air blast bring an increment of heat into the furnace, while higher oxygenated air only intensifies the generation of heat from the fuel within the hearth.

CONSTRUCTION.

The manufacturer who, in the swift march of progress and in the pursuit of an industry, the foundation of which is ever changing with altering raw materials, does not constantly take stock of his equipment and rejuvenate it to suit the times, will soon find himself outclassed by his competitors.

With the variety of possibilities which present themselves in the operation of furnace plants, many forms of construction can be worked out and many can be made successful. But every improvement should be inspired by one common aim, and that is to facilitate the utmost uniformity of practice in order to gain the highest quality of product and the greatest possible economy.

Stocking and Charging Apparatus.

For the sake of uniformity and to eliminate the danger of mixing various grades and the necessity of frequent burden changes, adequate space and equipment for the stocking of ores should be provided. This feature will allow of a greater latitude in selecting the most suitable furnace burden at a given time. If a cargo can be spread evenly over a large pile, so that any cross section of it represents a true average of all cargoes received during a shipping season, the furnace will receive the ores in the most uniform shape.

The bins should be so designed that the ore can be easily withdrawn under perfect control on the part of the operator. With sufficient slope and closely spaced gates to prevent the sticking of the ores in the corners, proper movement of the entire contents can be secured. Furnace troubles are always more frequent in winter than in summer, due to the difficulty of correct charging when the materials are frozen. In cold climates, therefore, the charging floor should be enclosed and the bins heated, preferably by waste gases.

In handling the coke, the main object should be to avoid abrasion. That charging system is preferable which transfers the coke from the ovens or railroad cars into the furnace

with the least number of drops. The coke can be charged by volume or by weight. The former method is independent of varying moistures in the coke, and automatically compensates for certain variations in quality, by delivering a greater weight of smaller, denser coke. This regulation, however, is not always correct, since smaller coke is not proportionately inferior, but it tends to equalize the error. Where the coke is uniform in moisture and furnace value, the weighing method will give excellent results.

The coke pockets should be made of ample capacity to avoid delays, and should be designed to keep all of the contents in motion and to avoid the accumulation of fines—a most frequent cause of furnace troubles. The dust should be eliminated by screens placed in the bin or at the gates.

The charging or larry car should preferably be large enough to hold a full charge of ore and stone. This saves labor and wear by decreasing the number of trips, and allows the furnace to be kept full with the least effort, even when driving fast, at the same time rendering the percentage of error in weighing smaller.

The skip hoist can be either of the single or the double type. The latter has the advantage of filling the furnace faster, but brings with it the difficulty of obtaining an even distribution between the right and left side of the furnace, which must be overcome by proper construction of the top. Materials dumped from an overturning skip bucket will arrange themselves more or less according to size, the coarse particles falling the furthest and the fines remaining behind. In order to avoid uneven distribution of fine and coarse materials, the design of the skip bucket, receiving hopper and top should be carefully worked out; as should also the range of skip travel and the speed of dumping, which should be under positively fixed control. The single skip allows the use of a cylindrical bucket with bottom discharge, dumping centrally over the bell and giving a correct distribution on the top of the furnace. But with that design it is necessary to correct the distribution in the bucket itself with regard to coarse and fine materials. This is a difficult matter and can only be accomplished by rotating the buckets.

This type of hoist, however, has the decided advantage of more carefully handling the coke charges, and for that reason has been largely adopted in Europe.

Top Construction and Stock Distribution.

The blast furnace top itself has been the subject of more variations in design than any part of the furnace. Besides being a gas seal, it has to fulfill the important function of proper stock distribution. It is difficult to accomplish this with a stationary top, and many furnace men prefer to abandon it in favor of rotating mechanical tops. Whatever type of top is selected, it must be borne in mind that a breakdown generally necessitates stopping the furnace; therefore the construction should be simple and strong. If a good distribution can be obtained without resorting to the complication of rotary mechanism, all the better. If deemed necessary to employ a rotating top, such a design should be selected which will give a satisfactory distribution, even if it should cease to rotate.

Many of the irregularities of stock distribution bear no relation to the design of the top; as for instance, the building up of ore on the big bell, which with Lake ores cannot be altogether prevented, even with the modern steep angles, and requires constant watchfulness, or the shifting of the furnace top relative to the furnace center caused by expansion and contraction; or the warping of the bell and hopper and the uneven wear of the stock-line. Neither can irregularities of charging—such as are caused by lack of care on the part of operator, severe weather, and many other causes —be corrected by any design of top. It will be seen, therefore, that a rotating top is by no means the cure of all evils. Careful supervision, constant vigilance, a regular and frequent inspection, are the only safeguards and should be practiced regardless of the type of top in use.

With a uniform distribution on the big bell, the next question is how the charges should best be arranged in the stock column. There are two opposite methods of depositing the materials in the furnace. The one, which is used abroad, but not in this country, consists in raising a

cylindrical bell and allowing the charge to glide off the hopper towards the center of the furnace, there forming a cone with an apex of fines and a base of coarse materials, which gives the gases a tendency to ascend next to the walls. This is counteracted by using a comparatively small hearth with tuyeres projecting far in, or a central gas off-take, and frequently by special stock deflectors. In European practice the stock column is much more open, less fines and considerable lump ores still being used with large sized coke and stone. Under these conditions this charging method seems to give satisfaction; and in many places it is still adhered to, in spite of the great complication of design, especially when combining the central gas off-take with a mechanical top.

Under our conditions, using practically none but fine ores, in order to obtain uniform practice, the principal aim must be to prevent the channeling of gases. As it is their natural tendency to follow the walls where the stock is continually loosened by friction, we deposit the ores next to the wall, thus forcing the gases to the center. In order to accomplish this we use a method opposite to the one described, lowering a large conical bell and dumping the charges against the furnace wall, the finer materials remaining there on a higher ridge, the coarser ones rebounding and rolling toward the center. This opens up the stock column in the center and serves the same purpose as a central gas off-take, only in a milder form. A recent experiment made at South Works with a central tube, showed conclusively that this arrangement is too radical for Mesaba ores.

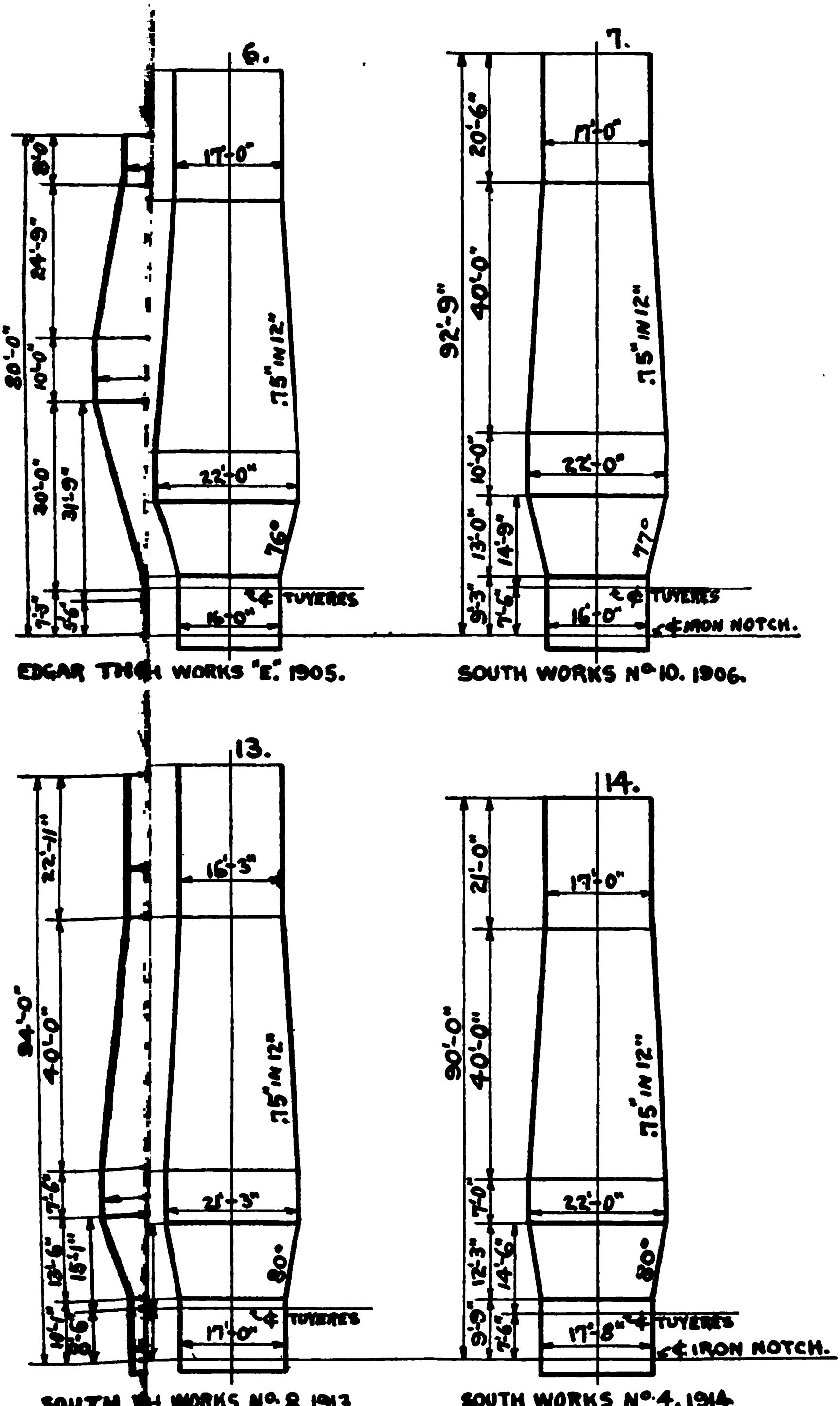
For the opposite purpose, that of loosening the stock next to the wall, various modifications of the plain bell have been tried. Such attempts originated in the early days of Mesaba practice, when it was thought that the formation of scaffolds could be avoided by placing less fines next to the wall. Designs of this kind have mostly been abandoned, as it was soon found that the evil of gases channeling along the walls and unreduced ores descending in the center, with high fuel consumption and buckshot iron as the result, was too high a price to pay for keeping the walls clean.

The plain bell with the gas off-takes at the periphery of the stack is evidently the best and by far the simplest design under our present conditions of raw materials. The problem to obtain a free working furnace on Mesaba ores could, however, not be solved until the correct furnace lines were established.

Development of Furnace Lines.

Going back in history, when Mr. James Gayley, in 1890, read before the British Iron and Steel Institute his memorable paper on the development of American blast furnaces, he outlined the trend of improvements in his concluding remarks by stating that in the last decade there had been three steps: First, in 1880, the introduction of rapid driving, with large outputs and high fuel consumption; second, in 1885, the production of an equally large amount of iron with a low fuel consumption, by slow driving; and third, in 1890, the production of nearly double that quantity of iron, on a low fuel consumption, through rapid driving. Mr. Gayley himself, who was then in charge of the Edgar Thomson furnaces, was largely responsible for this progress. Much credit also belongs to the management of the Illinois Steel Company, who on their Union and South Chicago furnaces made the best yearly fuel records of that period.

In the early eighties the linings at the Edgar Thomson furnaces had boshes half way up the stack; as, for instance, furnace "D," shown in Fig. 1 in the attached chart of furnace lines. This construction was taken over from the charcoal and anthracite practice with hard ores. It was realized that with coke as a fuel and with softer ores, much more rapid driving was not only possible but highly desirable, if it could be done without an increase in fuel. The furnace lines were conformed to this idea and the boshes lowered from 30′ to 20′, in the period covered by Mr. Gayley's paper. A furnace of this type is illustrated in Fig. 2, showing furnace "F" at Edgar Thomson in 1889. By the rapid yet consistent development of furnace lines and practice in this direction, and by strengthening his blowing equipment



FIGS. 1–14 egie Steel Company and the South Works, Illinois Steel Company.

accordingly, Mr. Gayley was himself able in a few years to surpass the predictions made in his paper. By 1894 the output of these furnaces had been increased to an average of 400 tons per day with a coke consumption of less than 1,900 pounds. This was accomplished by raising the stack from 80′ to 90′, lowering the bosh to 15′, increasing the size of the hearth to 13′, thus maintaining the previously established 75° bosh angle. A furnace of that type is shown in Fig. 3, giving Edgar Thomson furnace "H" in 1894.

A few years later Mesaba ores entered into the problem. In lowering the bosh and raising the furnace to 90 feet, still maintaining the 16-foot stock-line, the angle of the inwall had become steeper (see Fig. 3), and this had the tendency to retard the descent of the charges. The next step taken, therefore, was to increase the batter in the stack, which could be accomplished by narrowing the stock-line and lengthening the straight top section, or by widening the bosh. At the same time the advantage of still lower boshes was realized. These two developments together resulted in the type of furnace shown in Fig. 4, giving the lines of furnace "E" at Edgar Thomson in 1900. Furnaces of this type were able to produce 500 tons of iron per day on a burden of one-third Mesaba ores, but it was difficult to maintain uniform practice owing to accumulation of stock on the flatter bosh. This suggested the return to the 75° bosh angle by the use of still larger hearths, a step which was not taken without hesitation, as we feared an insufficient penetration. But no difficulty of that kind was experienced, and furnaces of this type marked quite an improvement, by establishing the average yearly putput of 500 tons per day on 50 per cent. of Mesaba ores with uniform practice. Such a furnace is illustrated in Fig. 5, giving Edgar Thomson furnace "K," built in 1902, which in 1903 averaged 539 tons of iron on 1985 pounds of coke. I have given the Edgar Thomson furnaces as an example, as they were representative of this development and, together with the Duquesne furnaces, established the best blast furnace records of that period.

Similar lines, consisting of a 16-foot stock-line, ¾ inch

to the foot batter of the inwall, a 22-foot bosh, 14′ 6″ to 15′ 6″ hearth diameter and a 75° bosh angle, were quite generally adopted on 90 and 100-foot furnaces using Mesaba ores. The percentage of these ores in the burden was gradually increased up to 70 per cent. in the next five years, but not without a distinct increase in coke consumption, as shown by the following figures representing the averages of a large number of American furnace plants using Lake ores:

Year	Per Cent. Mesaba	Lbs. Coke
1902.......	43.8	2,155
1903.......	50.3	2,191
1904.......	55.0	2,239
1905.......	61.0	2,275
1906.......	65.2	2,343
1907.......	68.7	2,362

The first experience with these ores had clearly shown that on account of their reducibility, they could be smelted rapidly and with a low fuel consumption, providing the furnace could be made to work uniformly, and the walls could be kept clean. The more regular, faster movement of the stock—by offering less opportunity for the gases to channel, and a more intimate contact and better heat exchange between ores and gases—allows a heavy burden to be carried in spite of the faster driving. The zone where the materials become plastic is kept at a uniformly low level, and there is less danger of scaffolds forming above the bosh. The task, therefore, is to design a furnace in such a way that the least resistance is offered to the free travel of the stock. With the proper batter already established, the chief impediment remains the bosh. As the melting zone is lowered, the bosh must follow, otherwise the materials will strike the inverted angle before the proper shrinkage through fusion takes place, causing the furnace to hang. Furthermore, a steeper angle should facilitate the stock movement in the bosh, and should, in conjunction with an increased hearth diameter, tend to keep the materials loose in arriving at the tuyere zone, allowing a free penetration

by the blast and preventing high blast pressures. The bosh seemingly has but one important duty—that of retarding the melting ores, so they will not run ahead of the coke and darken the tuyeres by reaching them before being properly prepared. These ideas were embodied in successive linings of the furnaces at South Works by increasing the hearth diameter up to 17′ 8″, decreasing the height of the bosh above the tuyeres below 12′, and steepening the bosh angle to 80°, a development which is clearly shown by Figs. 8–14 on the table of furnace lines.

In the latest models of these furnaces the bosh is no longer a conspicuous part and there is nothing to indicate that we have reached the limit in low and steep boshes, simply by further widening the hearths and without resorting to such means as the elliptical furnace. The hearth diameter, and not the bosh diameter, must to-day be recognized as the determining factor in influencing the rate of output. In designing new lines, the hearth dimensions should be established first, according to the desired production. By adding a bosh of correct height and angle, the bosh diameter automatically results.

As will be seen on the table of lines, stacks of different heights are in operation at the South Works. Whereas laboratory tests show that Mesaba ores can be completely reduced in a few hours by furnace gases at suitable temperatures, actual conditions are different. Practical experience proved that even with these easily reduced ores it takes considerable time, first, to thoroughly preheat every particle in a large bulk of ore, and then to bring it into contact with the volume of gases required to complete reduction. This led to a gradual increase in the height of stacks as the output was increased. Experience seems to show quite clearly that, for Mesaba ores, the proper height is 90′.

A greater height of the stack than that necessary to accomplish the desired reduction is not only useless, but detrimental by extending the zone where the coke is attacked by CO_2, and unnecessarily increasing the blast pressure. Furnaces which are too low compared to their hearth diameter have too low a blast pressure to give a proper penetration

in the combustion zone, if driven at the rate most suitable for economical reduction. If higher blast pressure and better penetration are obtained by increased wind volume, the zone of fusion rises and the time available for preheating and reducing the ore charges becomes too short, resulting in an excessive proportion of "direct" reduction by solid carbon. Furnaces operated in this manner are able to produce as large, or larger, tonnage than similar stacks of greater height, but will invariably show a higher fuel consumption. The practice of carrying the stock-line at a lower level has the same effect—the tonnage is increased at the expense of fuel consumption, except where the furnaces are too high, in which event they should be cut down rather than jeopardize uniform distribution and life of lining.

The diameter of the stock-line should be carefully chosen to correspond with the hearth and the prospective volume of wind. It should not be appreciably smaller than the hearth, otherwise the dust loss when using fine ores will be excessive. Neither should it be materially larger, as it would be difficult to attain the desired batter of the inwall without extending the cylindrical top section too far down, or inserting too high a cylindrical section above the bosh, both of which are liable to interfere with the smooth travel of the stock. The stock-line approximately determines the size of the bell. With Mesaba ores a bell of from 3′ to 5′ smaller diameter than the stock-line has given the best results. The method of charging has some influence on this relation.

The number of tuyeres, if kept within certain limits in proportion to the size of the hearth, is of little importance, since not their number but their combined free area determines the degree of penetration with a given wind volume. At the South Works ten and twelve tuyeres are used with equally good results on the largest hearths.

The relative position of the tuyere level, cinder notch and tapping hole deserve the most careful study. By increasing the height of the tuyeres above the cinder notch, a larger amount of slag can be held and the clogging of the tuyere zone with slag, which interferes with the combustion, is prevented. The greater the distance between cinder and

iron notch levels, the smaller the danger of the iron reaching the cinder notch and causing damage. With a fixed hearth diameter, this distance determines the maximum weight of individual casts. However, it cannot be increased except in proportion to enlarged output, otherwise the bath of iron, removed too far from the active tuyere level and held too long in the furnace, will cool and cause those manifold troubles due to physically cold iron, which affect furnace and steel works practice alike.

Since the character of the ores is changing all over the world, much in the same direction as in this country, the development of furnace lines in other countries will in all probability be similar.

Preservation of Furnace Lines.

Having established suitable lines, the next problem is to maintain them. Nothing contributes so much to the long life of a lining as a low fuel consumption and uniform practice. The hearth and bosh, which in the early days usually determined the length of a campaign by giving way first, are on our modern furnaces so efficiently cooled and so strongly armored that they outlast the lining in the stack. The ability to maintain the bosh indefinitely, by the insertion of cooling plates, led to many attempts to follow the same construction in the inwall. But the plates caused the lining to become corrugated between rows and to wear back above the top row, forming shelves highly inducive to scaffold formation. Furthermore, it was not an easy matter to so arrange the plates that they could be exchanged when leaking. Cooling plates above the mantle have only survived where they are placed from 18 to 22 inches back of the face of the inwall, and in this position they have not much effect in preserving the original lines. These difficulties led to the construction of thin lined furnaces on both sides of the water, from 9″ and 13″ of brick work in this country, and from 3″ to a mere coating of clay used on a few German furnaces. Very thin linings have only proved advantageous for making special grades of iron or when using coarser burdens.

In districts of high fuel consumption the adoption of thin

linings may have resulted in a coke saving by lowering the average stack temperature through cooling from the outside. Where heat concentration in the hearth and corresponding lower stack temperatures are reached by more efficient means, such intense cooling represents a direct loss. With Mesaba ores it is impossible to prevent the fine materials from building up on the cold shell, after the lining is worn away. Therefore the life of a thin lining is determined by the life of the brick work itself, and this is too short in the case of a 9″ or 13½″ lining to make this construction profitable.

Excessive thickness of a lining has no advantage, since before it wears out, the lines become so irregular that economical practice is impossible. From 22½″ to 36″ seems, therefore, the proper thickness. A good lining, if allowed to become properly seasoned and coated will wear slowly and uniformly, providing the stock and blast distribution is correct. A stack lined with a moderately thick lining does not require water cooling, but when the brick work does wear, the campaign can be prolonged by the application of water sprays without much deviation from the original lines.

The quality of the fire brick is the next important item in prolonging the life of a lining. The hearth and bosh brick are protected by efficient cooling; the top brick generally by wearing plates. The problem is to obtain brick for the lower inwall which will last without protection. Here they are exposed simultaneously to abrasion and high temperatures. They must, therefore, have a high melting point and yet be hard and tough. The quality of clays and their treatment, as well as the various methods of brick manufacture, enter here. Machine-pressed brick are especially well adapted to meet the requirements of a good inwall, and owing to their correct shapes can be laid with narrower joints. They have given excellent results at the South Works during the past five years, from six to eight hundred thousand tons of iron being obtained on a lining, and with good practice to the end. In Germany carbon brick are frequently used in the hearth and bosh, with varying results and opinions widely differing as to their value.

A great variety of wearing plates have been designed to protect the stock-line, but very few have proved successful. The plates should be made in small enough sections and of such metal and design that they will neither crack nor warp. To prevent their working loose and interfering with the distribution, they should be tied in with the brick work. Some furnace men prefer to avoid the complication of such arrangement by repairing the brick work at the stock-line during the campaign.

Stack Construction.

The strong, riveted, steel plate shell surrounding the brick work is one of the best features of our construction. It is now made so heavy that the lining can be laid quite close against it, insuring tight joints, which are forced to close with the expansion of brick work. The shell may serve the purpose of supporting the top ring, hopper and downcomer pipes; but the skip hoist and dumping mechanism should under no circumstances be attached to it. These must be supported independently to avoid shifting with the expansion of the furnace. The furnace shell protects the brick work and allows weak spots in the lining to be held for long periods by the application of water sprays In Germany furnace shells are found only exceptionally and on older furnaces. The construction commonly used there encircles the brick work with steel bands. Many stacks are cooled, sometimes up to the top, by open cast iron water boxes which are placed between the bands and generally extend to within a few inches of the interior face of the lining. For this construction is claimed the advantage of accessibility when repairs to the brick work are needed. In some instances German stacks have been practically relined without blowing out, by banking below the mantle. The furnace with a steel shell is certainly stronger and safer, and can be kept in blast under conditions which would force an open furnace out of operation. Our practice would seem to prohibit the German construction on account of high blast pressure, loss of gas, and danger of ruptures in case of heavy slips. In the bosh where we employ the

German stack construction, they often use a steel jacket, similar to the one employed in this country on Eastern furnaces using magnetites and imported ores. With Mesaba ores the more intense cooling of the water-sprayed jacket causes accumulations to form on the bosh, which periodically melt down, making the practice very irregular.

The gas off-takes should be located as high above the stock-line as possible, out of the path of the falling stock. There should be several, preferably four, and their area should be sufficient to prevent excessive velocity. In this manner, and by turning these off-takes upward before they lead down to the dust catcher, the amount of flue dust and fine coke carried over has been decidedly reduced. One or more good safety bleeder valves should be provided, so designed that they will give ample relief during heavier slips without allowing any coarse materials to be thrown out.

Gas Cleaning.

The dry gas cleaning system need only consist of one dust catcher of good size and an efficient centrifugal cleaner. These will eliminate practically as much dust as more elaborate arrangements, and are economical in construction and operation. A primary gas washing plant of sufficient capacity to wash all the gas for stoves and boilers should form part of every modern furnace plant. There is no question as to the value of washed gas for stoves, and a proper design of boiler settings, to allow of a free development of the flame and complete combustion before the gases strike the colder surfaces, will render it economical for boilers also.

Stoves.

With washed gas the problem of stove construction becomes comparatively easy. Small checkers can be employed and thereby the heating surface is increased sufficiently so that four large stoves will furnish all the heat required. With clean gas these can be kept in continuous service. They form a simpler layout and are preferable to five

smaller stoves on account of better heat economy, less radiation surface and fewer valves.

The latest innovations, which come to us from Germany, claim to increase the capacity and efficiency of existing stoves by using compressed air for combustion, or by installing heat interchangers in the chimney flue for preheating the air.

Blowing Engines.

When using fine ores, strong blowing equipment is essential to insure the delivery of a uniform amount of wind, even under conditions of high blast pressure. Gas engines of good design and liberal dimensions have proven to be especially adapted for this service, since the cost of blowing is but little affected by high blast pressures, whereas it can be made almost prohibitive in the case of steam engines in districts of high cost of fuel. The great economy of the gas-blowing engines has been a long established fact. Practice in recent years has proved their reliability in service, and has thereby definitely decided in their favor against reciprocating steam-blowing engines, except in a few localities favored by very low coal prices or at isolated furnace plants where the surplus gas is not utilized, and therefore has no value. With the gradually increasing cost of coal mining and the growing tendency to make economical use of the surplus gas, the gas engine will continue to enlarge its field of usefulness. The steam turbo blower may conquer a position in the localities least favorable to gas engines, owing to its low cost of installation, small space requirement and simple operation. However, practice has not yet definitely proved that it will deliver as constant a supply of air as the reciprocating engine, particularly when fine ores are used, and the resistance in the furnace is subject to considerable and sudden variations.

OPERATION.

Practical experience had developed the blast furnace to a remarkable degree of efficiency long before science attempted to shed any light on the process. In the old

days the blast furnace was regarded as much of a mystery, and only practical men, through spending most of their lives with it, were capable of successfully controlling its whims. Good furnace men of this caliber were naturally scarce, and being rather jealous of their knowledge they were reluctant to teach others what they had acquired through years of hard work.

It was not until the middle of the past century that men of science gave to the industry a clear understanding of the important reactions in the furnace. This at once led to the realization that the process could be scientifically controlled, and soon the chemical laboratory was universally called upon to assist in regulating furnace operation. Then started a gradual transformation of furnace practice and, to speak in medical terms, the former curative or surgical methods were replaced by preventive treatment. The composition of the charges being known, the analysis of the resulting product could now be determined in advance, and its quality controlled with far greater certainty.

With the better selection and preparation of raw materials, more suitable furnace construction, better blowing equipment and stoves, the furnace operation became more and more a science; the more accurate knowledge as to the causes and effects of the detrimental reactions enabled the furnace manager to more successfully counteract them. While it was the essential qualification of the old type of furnace man to be expert in getting a sick furnace out of trouble, a task at which he gained plenty of practice, nowadays scientific management is expected to keep the blast furnace out of trouble and through perfect control of raw materials and furnace practice establish a uniform, economical operation.

Blowing in.

Having established the correct lines the foundation of a successful furnace campaign is laid by the utmost care and caution in blowing in. After a thorough drying of the lining the fire should be lighted simultaneously and uniformly all around the hearth and be given the opportunity to penetrate quickly into the center of the furnace. Whether a

wooden scaffold is used for preheating the coke charges before they reach the bottom, or the hearth is filled with coke and a pipe is inserted through the tapping hole to carry part of the combustion downward, either method thoroughly heats the bottom and the first casts are of good grade and can be tapped without difficulty.

The proper stepping up in weight of burden and wind can only be established by experience. If in doubt, it is better to err on the slow side. In order to avoid channeling on the walls on the one hand, and building up on the bosh on the other, the tuyere area should be increased in proportion to the amount of wind blown.

To establish a low top temperature from the very first, the burden should be increased in advance of the wind. In this manner a new furnace can be made to carry the highest possible ratio of burden in the second week of operation. By gradually following with the wind volume and bringing higher blast heats into play, it is possible to maintain this heavy burden and reach a high production on a low fuel consumption with a comparatively small amount of wind blown. This practice saves the new lining and permits it to become thoroughly seasoned and hardened. The first slag should not be so acid as to scour the walls nor so basic as to accumulate on the bosh. It should be just "limey" enough to liberate graphite from the iron and form a thin protective coating on the brick work. To maintain a most nearly perfect slag, every preference in the selection of raw materials should be given to a new furnace. As the lining becomes older it becomes more seasoned and suffers less variations.

Furnace Practice.

After the furnace assumes its proper pace, which means such a rate of driving as can be maintained without decreasing the previously established maximum ratio of burden, there should be as few radical changes as possible. The most advantageous unit of burden charge must be established by experience for each type of furnace, as well as the best method of dumping, and these should be varied only if the necessity for a change is definitely proved.

Any variation in the temperature and analysis of slag and iron should be promptly recognized and counteracted, at first by applying the reserve heat, then, if proper diagnosis indicates the necessity, by decreasing the burden. It should be borne in mind that "a stitch in time saves nine," and a slight change in heat or a small decrease in burden, quickly applied, will generally prevent more serious trouble. Coke blanks should be avoided as much as possible, as strong remedies of that nature tend to make the furnace fluctuate and disturb the desirable working lines which previous economical practice has formed.

The average blast temperature carried on furnaces burdened with Mesaba ores seldom exceeds 1100° F., ranging far lower than the blast heats commonly applied in European practice, and also lower than on most of our Eastern furnaces using magnetic ores. This is due to the fact that with the easily reducible Mesaba ores very low fuel consumption can be attained with comparatively low blast heats, providing the distribution and the furnace lines are correct. In fact, it occurs that furnaces operating with high blast heats side by side with furnaces using low blast heats, will require more coke, simply because in the latter heating and reduction are carried on more economically. The frequent failure to obtain any saving with high blast temperatures, coupled with the other common experience of Mesaba furnaces refusing to "take" the high heats has at many plants resulted in delaying the improvement of stove equipment and gas washing, so that even where the value of higher heats is recognized they are now often not available.

The ability to use high blast temperatures is determined by three factors: First, the physical condition of the stock in the furnace; second, the chemical and thermal conditions in the hearth; and third, the CO_2 to CO ratio in the gas. The first condition is determined by the physical character of the raw materials, their distribution in the stack, and the furnace lines, all of which influence the permeability of the stock column. The second condition is influenced by the fusibility and fluidity, as well as volume and basicity of the

slag, which are generally determined by its duty of sulphur elimination. The third condition depends on the reducibility of the ores and the grade of iron to be produced.

Uniformity in every respect will greatly facilitate the use of high heats, even if one or the other of the premises mentioned should not be favorable. A sudden increase of blast heat raises the hearth temperature and renders the slag more "limey" by reducing more silicon into the iron. With a dense stock column this will frequently cause an increase in blast pressure and will retard the action at the tuyeres, a condition which is aggravated by coke of slow combustibility and too small a cinder volume. A low percentage of slag will not only exaggerate the variations in analysis but will prevent the free descent of the stock and the desired penetration of the hearth, particularly when the shrinkage of the materials in the bosh through fusion is less than that required by the bosh angle. With high or flat boshes a greater cinder volume is necessary to insure smooth working with high blast heats than with low steep boshes.

Eventually the movement of the charges may stop altogether, and the furnace hangs. By then lowering the blast temperature the fusion zone can be extended until it reaches the plastic, limey agglomerations suspended in the bosh; and with the reduction of hearth temperature the slag again becoming more acid and fluid, the materials begin to melt and the stock column resumes its regular movement.

The greater the number of different elements contained in a slag the greater is its fluidity. This depends on the ability of the various components to enter into solution with each other, and must not be confused with the fusibility of slags. The latter is mainly determined by the chemical composition, and varies greatly with the proportion of the different components and their tendency to form new combinations with each other. The same element which in certain percentages will render the slag more fusible will, if present in different proportions, render it highly infusible. It is one of the blast furnace operator's chief duties to so select his burden that the resultant slag will have the most suitable fluidity as well as fusibility. A transgression be-

yond the established range of desirable fluidity and fusibility, in either direction, is detrimental.

To permit high blast temperatures being carried and enable the furnace to work freely with a low melting zone, the slag must be kept uniformly acid. Once the melting process is carried too high up, the original bosh line is raised, the brick work above the bosh wears back, the bosh becomes too high, and any attempt to again lower the zone of fusion by the application of high heats and increased burden results in irregular operation by suspending the unmelted stock on the previously formed angle. This is why high heats cannot generally be used on a worn lining.

Under otherwise favorable conditions the use of high heats is often a matter of education on the part of the furnace crew. With the unavoidable variations in raw matèrials it is easier to operate on lower blast heats a lighter burden, and with richer gases, because of the greater margin of safety with plenty of heat held in reserve. The use of very high heats requires constant watchfulness, and any slight change in the furnace must be quickly perceived and counteracted.

The cost of heating the air increases with the degree of temperature, and simultaneously the rate of coke saving decreases; so that in practice the economical limit of high blast heats generally lies below the theoretical one, which is reached when the gases lack the necessary preheating and reducing power. In the case of Mesaba ores, which are easily and quickly reduced by the gases, fast driving is possible without running into "direct" reduction; and lean gases, low top temperatures, and a low fuel consumption are reached by the use of moderate blast heats, as illustrated by the following data of all the South Works furnaces of the Illinois Steel Company for a year:

AVERAGE PRACTICE, MAY 1, 1913, TO MAY 1, 1914.

POUNDS PER TON OF IRON.

	Avg. Daily Prod.	Ore Scale Cinder	Coke	Stone	Excess of Scrap Used Over Prod.	Flue Dust Prod.	% Mesaba Ore	Actual Yield
Bessemer	501	4,136	1,927	863	23	207	73.9	53.63
Basic	493	4,471	1,961	849	51	160	85.5	49.08

	Cu. Ft. of Air Per Min.	Blast Pres.	Temperature		Analysis of Iron			Analysis of Slag			
			Blast	Top	Sil.	Sul.	Mn.	SiO_2	Al_2O_3	CaO	MgO
Bessemer	48,850	15.3	1,068	330	1.39	.034	.68	35.60	13.44	46.85	2.06
Basic	45,660	16.3	996	266	.97	.038	1.72	34.71	14.48	45.50	3.40

To indicate the extent of coke saving which is obtained, even in Mesaba practice by the application of higher heats than the average shown above, on furnaces with favorable lines, the following data giving the monthly practice of Bessemer furnaces using less than 1,750 lbs. of coke per ton of iron are of interest:

POUNDS PER TON OF IRON.

	Avg. Daily Prod.	Ore Scale Cinder	Coke	Stone	Excess of Scrap Used Over Prod.	Flue Dust Prod.	% Mesaba Ore	Actual Yield
"E" Fce.:								
Sept. – '13	525	4,012	1,691	677	88	175	92.9	53.24
Oct. – '13	514	4,047	1,711	774	113	171	93.0	52.85
Dec. – '13	536	3,852	1,705	780	109	201	83.7	55.69
No. 4 Fce.:								
Mar. – '14	518	4,062	1,744	781	17	193	67.4	54.76
Apr. – '14	543	4,003	1,702	752	73	227	66.5	54.40

	Cu. Ft. of Air Per Min.	Blast Pres.	Temperature		Analysis of iron			Analysis of Slag			
			Blast	Top	Sil.	Sul.	Mn.	SiO_2	Al_2O_3	CaO	MgO
"E" Fce.:											
Sept. – '13	47,750	15.1	1,225	317	1.30	.034	.61	37.25	11.21	47.58	2.16
Oct. – '13.	46,390	16.2	1,251	306	1.48	.043	.60	37.40	11.47	46.55	2.03
Dec. – '13.	45,510	15.7	1,250	300	1.33	.041	.71	36.12	11.48	48.46	1.97
No. 4 Fce.:											
Mar. – '14	41,140	15.7	1,170	274	1.29	.025	.59	33.48	15.67	45.39	3.85
Apr. – '13.	42,950	16.0	1,196	283	1.23	.027	.56	34.63	15.01	45.63	2.83

Where less reducible ore mixtures are used, part of the reduction must be accomplished by solid carbon, the top

gases are richer, and a much greater margin is left for fuel saving with high blast temperatures.

Uniform furnace practice demands that the blowing engines be so governed as to deliver a constant quantity of air and not to maintain a constant pressure. The smelting of fine ores requires still greater care and accuracy in this respect, and this has led to the effort to deliver a constant weight of oxygen to the furnace at all times. Where the Gayley Dry Blast is used, this is accomplished simply by maintaining a uniform speed of the blowing engines. Reciprocating engines running on natural air can be made to deliver a constant weight of oxygen by varying the revolutions according to atmospheric changes. To derive the benefit of lower temperature and moisture, the air should be drawn from the outside of the engine room. Turbo blowers can be governed by a regulating device in the air inlet, which is supposed to automatically deliver a constant volume of air. It does not correct for moisture and temperature variations, nor does it seem likely that such a fine regulation can ever be attained with a device which has to correct the much greater effect of varying resistance in the furnace.

With all of these adjustments there still remains the error of the varying volumetric efficiency of the blowing tubs, leaky valves, mains, stoves and connections. These are generally in excess of any assumption. Even when proper deductions for clearance and valve losses have been made, the actual air required to burn the carbon contained in the charges and available for combustion at the tuyeres is less than that calculated from the blowing engine revolutions. Engines equipped with modern automatic valves show better results in that respect; and turbo blowers, by obviating the pulsation, give the highest actual delivery. For better control it seems highly desirable to measure the air for each furnace. The practical possibility of installing flow meters in the cold blast main is now being demonstrated at South Works, where an instrument has recently been put in service and is giving very promising results. In Germany it is the practice at several plants to blow with all the gas

engines into a common main for all furnaces of a group. The engines are operated at the most economical speed. The blast pressure is held uniform and slightly above the maximum furnace pressure. The volume of air for each furnace is regulated by an automatic valve in connection with a flow meter. This system should give good results at plants where the blast pressure varies but slightly, and in connection with gas engines which, on account of their low gas consumption, can be operated against an increased blast pressure without materially affecting the blowing cost. With steam-blowing engines, where the fuel consumption constitutes the largest item of cost, and in practice where the blast pressures vary, this method cannot be considered.

A furnace will, at times, without any change in the wind or raw materials, start to drive faster, taking more charges. In this case the carbon introduced with the additional rounds of burden is consumed in the "direct" reduction with the ores or by solution in CO_2. In the combustion at the tuyeres the constant weight of oxygen blown can combine with only a certain constant amount of carbon to CO, generating a fixed quantity of heat. Therefore, the additional coke charged must be consumed by the oxygen in the ores or dissolved by CO_2. Under these conditions a furnace will run cold, unless sufficient blast temperature is applied to balance the heat lost by the "direct" reduction and solution in CO_2 as well as that required for the melting of the additional ore charges. If enough blast heat is not available, the wind must be diminished in order to re-establish the former equilibrium of "indirect" and "direct" reduction, and avoid the necessity of lightening the burden.

Practice on Various Grades.

Blast furnace operations are comparatively simple where the same grade of iron is made continuously. The practice becomes more intricate when frequent changes from one grade to another are required. Without good furnace lines it is impossible to vary the grades without loss of quality and economy.

In merchant furnaces generally much smaller hearth

dimensions are found than those which have been developed on modern furnaces connected with steel works, and higher or flatter boshes are frequently chosen, the former to accommodate the higher melting zone on foundry grades, and the latter to facilitate the production of basic iron, recognizing the value of low boshes but perhaps not the advantage of larger hearths. Such designs are poorly suited for successful operation on varying grades, particularly those which require basic slags. Merchant practice, above all others, demands lines which keep the furnace walls clean. The low, steep bosh accomplishes this, while the larger hearth favors uniformity of product and fuel economy. Foundry grades, spiegel, ferro-silicon, and ferro-manganese are being made in the large hearths of modern furnaces with excellent results, surpassing those obtained on smaller furnaces especially designed for such practice.

In producing these grades, the first step is to so modify the physical and chemical quality of the slag as to make it most favorable to the transfer of the desired elements into the iron, and to the elimination from the iron of those ingredients which are not wanted. For instance, in high silicon Bessemer or Foundry practice, a much lower fuel consumption can be obtained if, by a decreased proportion of bases in the slag its ability to retain silica has been lessened, thereby favoring the reduction of silicon into the iron. Lower fuel consumption and higher blast heats will then assist in concentrating the melting zone and maintaining a high hearth temperature, which will increase the ability of the leaner slag to dissolve and retain the sulphur, resulting in a uniform grade of low sulphur iron. The production of high grades of ferro silicon is made possible only by a large preponderance of silica in the burden and slag. Even then, the highest blast temperatures are required to reduce economically large quantities of silicon.

In spiegel and ferro manganese practice, where it is desired to reduce the maximum amount of manganese into the product, with the least loss of manganese in the slag, a very basic slag must be carried. By the utmost concentration of heat in the hearth through the use of the highest

blast temperatures, the slag can be kept sufficiently fluid, in spite of being very "limey," and the manganese in the slag can be held uniformly below 6 per cent. The loss of manganese in the gases, which occurs more or less in proportion to the top temperatures, is reduced to a minimum by concentrating the zone of fusion and thereby lowering the top temperature. By charging suitable percentages of raw coal, the distillation of which consumes heat, the top heats can be still further reduced. The temperature of the escaping gases can in this manner be kept below 600 degrees F., even when producing 80 per cent. ferro-manganese; and the gases, which are generally dark yellow or brown, can be observed issuing from stove and boiler stacks with but the faintest tint of yellow.

Below are some results recently obtained on No. 1 furnace at the South Works, which illustrate the practice just described:

	Total Tons	Daily Average	Coke per Ton	Coal per Ton	Temperature Degrees Fahrenheit		Average Grade	Per Cent Mn. in Slag
					Blast	Top		
Ferro-Manganese, Dec., 1913	3870	125	3896	288	1470	550	80% Mn.	5.81
Spiegel, Feb.–Mar., 1914	6528	272	2858	...	1167	607	19% Mn.	2.18
Ferro-Silicon, March–April, 1914	7396	161	3867	...	1214	676	11% Sil.°	....

On the same lining this furnace had previously produced 644,815 tons of Bessemer, basic, spiegel, ferro-silicon and ferro-manganese, which illustrates the possibility of making use of old linings for the manufacture of special grades.

Blowing Out.

A furnaee campaign, however, should never be continued after the lining has become so warm that further economical practice is impossible. The expenditure for relining can be made comparatively small if the furnace is constructed with this point in view, and can generally be saved in a few months by the lower cost, resulting from better practice.

The unwarranted prolongation of furnace campaigns on worn-out lines is often a source of enormous losses in the manufacture of iron, and one which seems to be frequently overlooked in the effort to achieve a large production on a lining. It is poor policy to set a standard tonnage for a campaign, since one of 300,000 tons may be more destructive to the furnace walls than another of twice that tonnage. The economy of practice alone should determine the end of the furnace campaign. The vainglory of accumulating a large tonnage on a lining is a poor compensation for losing money, as well as the furnace organization's pride in a low fuel consumption.

The possibility of maintaining low fuel consumptions on furnace campaigns, and still reach high tonnages, is demonstrated by the following records as at May 1st of present campaigns of blast furnaces at the South Works of the Illinois Steel Company:

	Total Production	Average Coke Consumption
No. 1 Furnace—Operating on special grades.		
No. 2 Furnace.........	475,442 tons	2,044 lbs.
No. 3 Furnace.........	788,512 tons	2,056 lbs.
No. 4 Furnace.........	36,414 tons	1,806 lbs.
"E" Furnace.........	417,117 tons	1,939 lbs.
No. 5 Furnace.........	41,252 tons	1,944 lbs.
No. 6 Furnace.........	247,572 tons	2,116 lbs.
No. 7 Furnace.........	279,639 tons	1,975 lbs.
No. 8 Furnace.........	223,175 tons	1,923 lbs.
No. 9 Furnace.........	593,007 tons	2,028 lbs.
No. 10 Furnace........	205,698 tons	2,005 lbs.

Furnaces Nos. 2, 6, 9 and 10 were blown out last winter on account of business conditions and not on account of worn-out linings. The others are still operating.

In blowing out, the temperature of the escaping gases should be kept so low as not to cause any damage to the furnace top. This is accomplished by spraying water on the bell and the descending stock, and gradually decreasing the wind volume. Accumulations on the walls of stack and bosh should be cleaned off in the process of blowing out by using an acid slag and short tuyeres. A suitable quantity of fine materials, such as boiler ashes or granulated cinder,

charged on top of the final rounds of burden, will keep the blast pressure sufficiently high, even when the stock line approaches the tuyere level, to allow most of the iron and slag to be lifted out of the hearth during the last cast. This applies only to American practice where the tapping hole slants downward. In this manner a large amount of the labor for cleaning out the bottom can be saved. The danger of gas explosions is avoided by filling the gas flues with steam before any air is allowed to enter.

Furnace Gas, Its Output and Utilization.

By modern utilization of the by-products, their disposal, formerly a source of expense in the operation of a blast furnace plant, has been converted into a handsome profit. The furnace gas is the most conspicuous in this respect. It has become a potent, economical factor as the source of power for steel works and other industries or public utilities located in the district.

The rate of gas production and its total B.T.U. value is a function of the coke consumption, as well as of the pig iron output. Extensive tests were conducted at the South Works to establish the relation of these items and to determine the amount of surplus gas for the production of power which would be available from our furnaces under various conditions of practice. For two full years (1911 and 1912) on all blast furnaces of the plant making basic, Bessemer and spiegel, continuous gas samples were taken and analyzed every 24 hours, and the results were averaged for each month. The averages are plotted on Chart I. (page 60), each point representing a full month's operation of a furnace. On these averages and the monthly performance of the furnaces, the diagrams of Charts II. to V. are based. These show successively the relation of gas volume and heat value to coke consumption and that of pig iron output to coke consumption, volume and total calorific value of the top gases.

These diagrams show that the gas volume per ton of iron and the calorific value per cu. ft. of gas increase with higher coke rates, but that the fuel consumption, in our practice, decreases with an increase in output. It is this

latter relation which turns downward the curves on Chart IV., representing the amount and calorific value of the top gas per unit of time. These and the lines of Chart V., which

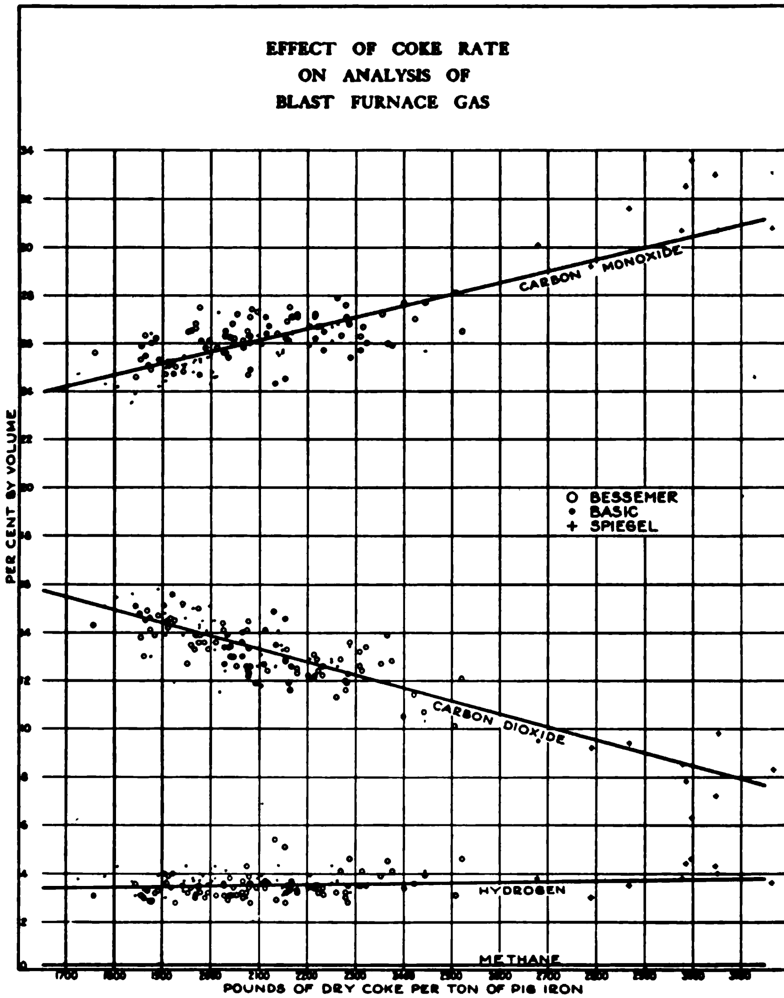


CHART I.

show the same items per unit of product, distinctly prove that with larger output, the amount of heat per ton of iron carried off with the top gases, decreases, and clearly demonstrates the economy of fast driving with Mesaba ores.

The heats of combustion of the constituent gases were taken as follows, sensible heat due to top temperatures not being considered:

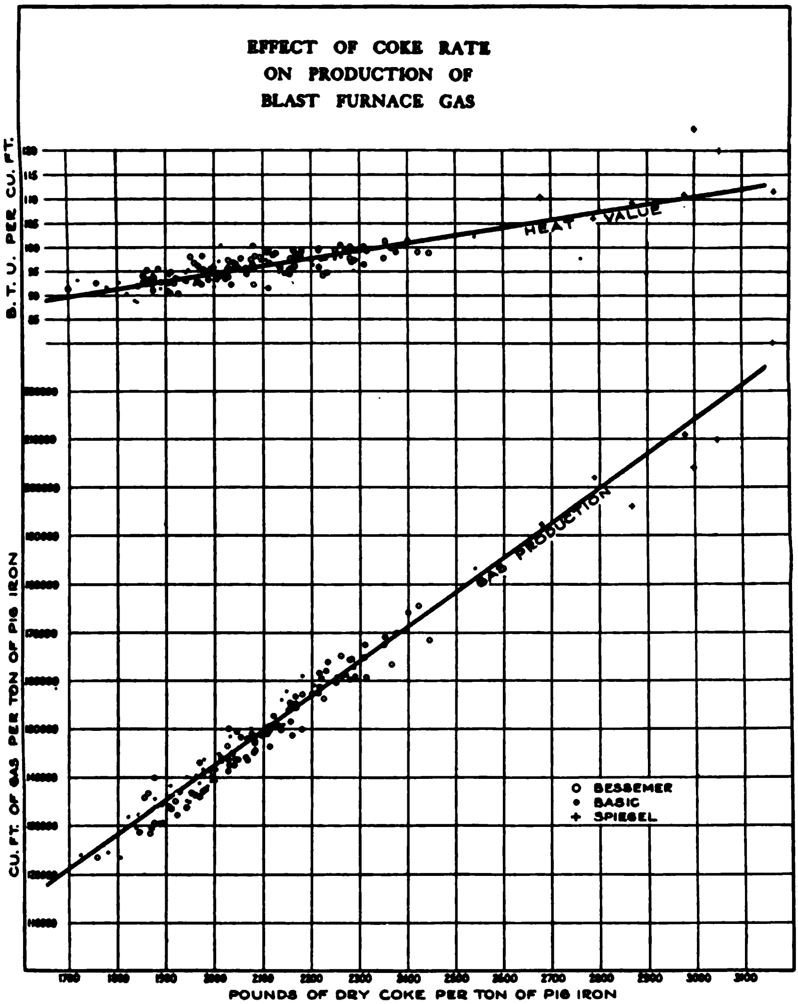


CHART II.

CO..................	324 B.t.u. per cu. ft.
H_2..................	275 B.t.u. per cu. ft.
CH_4.................	915 B.t.u. per cu. ft.

The computations of gas production, Chart II., are made on the basis that the carbon charged as coke reappears in

the gas, assuming that the weight of carbon in the limestone is equal to the carbon in the pig iron and flue dust produced. The error of this assumption is less than 1 per cent.

The method of calculating the volume of gas is as follows:

Tons Bessemer iron produced per day..	552.5
Coke rate, pounds per gross ton........	1,988
Carbon in coke........................	88.72%
Analysis of gas:	
CO............................	25.8 %
CO_2............................	13.6 %
H_2............................	3.0 %
CH_4............................	.2 %
N............................	57.4 %
B.T.U. per cu. ft.................	93.3

Cu. ft. gas per ton of iron,

$$\frac{1{,}988 \text{ lb. coke} \times 88.72\% \text{ C}}{(25.8\% \text{ CO} + 13.6\% \text{ CO}_2 + .2\% \text{ CH}_4) \times .0315} = 141{,}400$$

The constant 0.0315 is the weight of carbon in a cubic foot (at 29.92 in. and 62° F.) of any gas in which there is one atom of carbon per molecule. All volumes are referred to 62° F. and 29.92 in. barometer.

The following formulæ are based on these investigations, R being pounds of dry coke per ton of pig iron and T being tons of iron per 24 hours.

$$\text{B.T.U. per cu. ft.} = 0.016 \text{ R} + 62.5. \quad (1)$$

$$\text{Cu. ft. gas per ton iron} = 71.4 \text{ R}. \quad (2)$$

$$\text{B.T.U. in gas per ton iron} = 1.143 \text{ R}^2 + 4{,}462.5 \text{ R}. \quad (3)$$

$$\text{Cu. ft. air at tuyeres per ton iron} = 51.4 \text{ R}. \quad (4)$$

$$\text{Cu. ft. air per minute} = .0357 \text{ R T}. \quad (5)$$

Chart III. shows the relation of coke rate and tons iron per day during the performance of the same furnaces for the same period as shown on Charts I. and II. The mean line drawn through these points has the formula

$$\text{T} = 1{,}090 - .2875 \text{ R} \quad (6)$$

or,

$$\text{R} = \frac{1{,}090 - \text{T}}{.2875} \quad (7)$$

Combining (7) with (2) and dividing by 1,440 minutes gives

$$\text{Cu. ft. gas per min.} = 188.1\ T - .1{,}726\ T^2 \qquad (8)$$

which is plotted on Chart IV. Further, by combining (8) with (1) and (7) gives

$$\text{B.T.U. per min.} = 23{,}155\ T - 31.705\ T^2 + .00960\ T^3. \qquad (9)$$

From (2) and (7)

$$\text{Cu. ft. gas per ton iron} = 270{,}710 - 248.35\ T.$$

While from (3) and (7)

$$\text{B.T.U. per ton iron} = 33{,}350{,}000 - 45{,}670\ T + 13.83\ T^2.$$

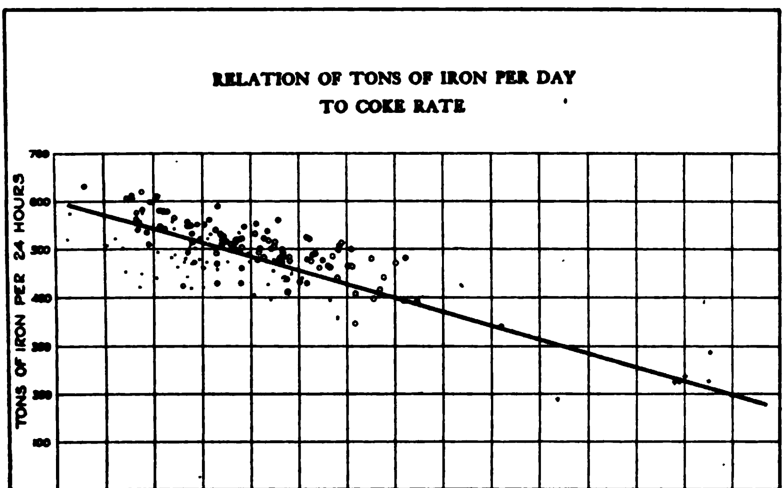


CHART III.

The curves on Chart IV. show that the amount of gas, and still more, its calorific value, is practically constant within the range of our usual daily variations of pig iron production. This feature is of special interest where other industries rely upon the blast furnace for a constant supply of power.

The nitrogen content of the gas, determined by difference, if plotted in conjunction with the CO_2 to CO lines on Chart I., forms an almost horizontal line. This indicates that

the air requirement per unit of carbon, in the practice represented by the test period, was almost constant. Even when the proportion of "direct" reduction was increased through fast driving, this evidently did not decrease the amount of carbon which reached the tuyeres appreciably more than

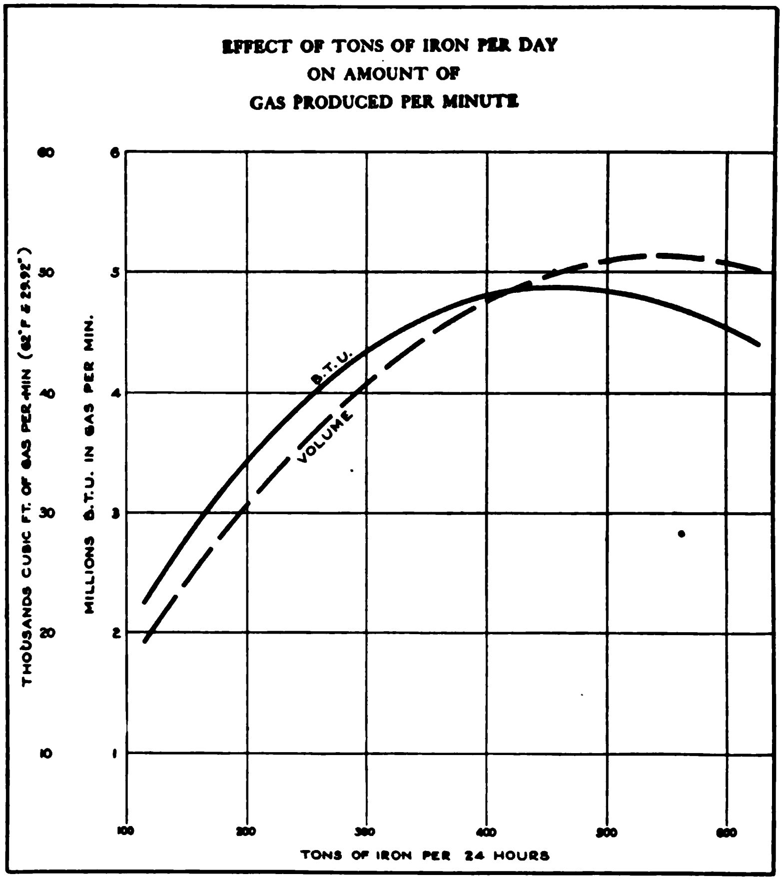


CHART IV.

the dissolution of carbon by CO_2 in the practice with higher fuel consumption, due to poorer coke or wornout lines. In the former case, the carbon, as well as the heat consumed by "direct" reduction, was replaced by an increase in blast temperature, smaller radiation losses, and other advantages

derived from fast driving. In the latter, the loss of carbon was replaced by an increase in coke consumption.

Recent experiments at South Works and Gary have proved that in times when there is no demand for the pig iron, the production of power can be maintained by con-

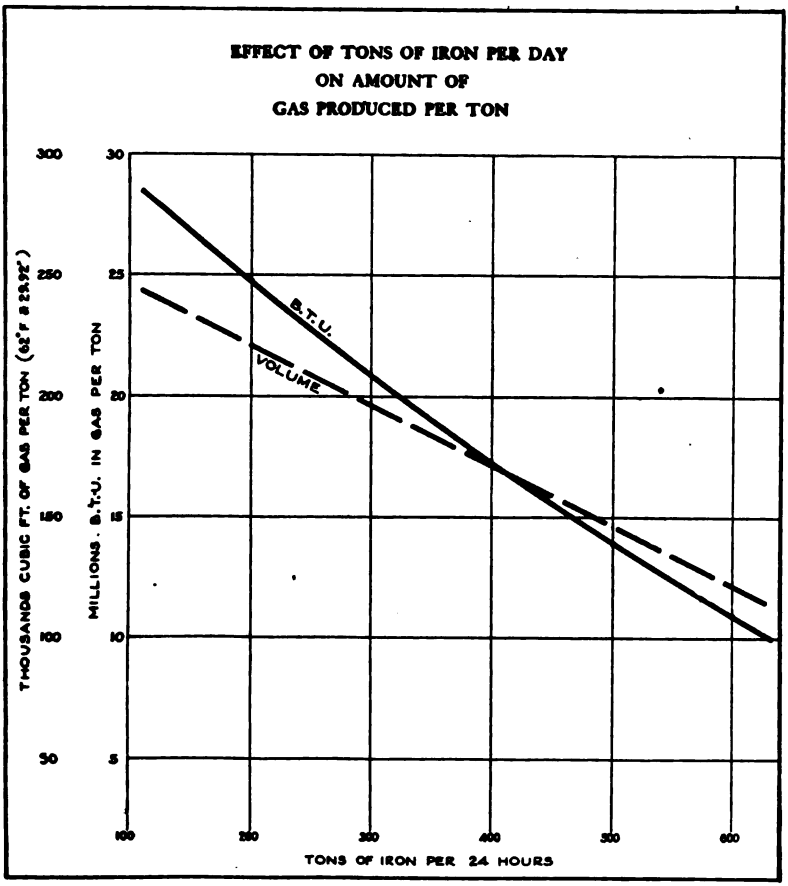


CHART V.

verting a furnace stack into a gas producer, charging a mixture of coke, coke breeze and coal with open hearth and other waste slags as flux.

The latest development in Germany is the mixing of blast furnace and coke oven gas. By automatic regulation the most desirable heat value can be uniformly maintained.

The use of furnace gas or mixed gas for the heating of coke ovens makes a larger amount of the richer coke oven gas available for outside use, as for instance, municipal heating and lighting. The higher and more constant heat value of the mixed gas also solves the problem of efficient gas engine operation in large electric power plants, where uniformity of speed is the first requirement.

Slag as a By-Product.

Many blast furnace slags can be used for the production of cement, an industry which has been developed to large proportions in this country and abroad. Another profitable outlet for the slag, frequently found in Germany and undoubtedly applicable to many plants in this country, is the manufacture of high grade building brick.

Possibilities of Labor Saving.

The increased output of modern furnaces, coupled with the many labor saving improvements, has lowered to a remarkable extent the cost of operation per ton of iron. The vast array of common labor which formerly performed the hardest, roughest, and most dangerous duties around a blast furnace, has been eliminated, and their places have been taken by fewer men of higher skill. The operation of charging our furnaces has reached such a remarkable degree of perfection that one man is able to fill a 500-ton stack and do it with greater accuracy, better control, and less physical effort than the host of men formerly required.

Suitable hearth construction has decreased the daily number of casts. At several plants only four casts are made in twenty-four hours. At the South Works three casts per day is the rule, 150 to 200 tons and more being tapped at a time. It is quite possible that in the future, with further enlargement of the crucible, no casts will have to be made on the night turn. Big ladles and mixers of large capacity are indispensable in this development. The latter have the further advantage of eliminating the most objectionable and wasteful part of blast furnace operations—the casting

in sand beds or pig machines and the remelting of a considerable portion of the product. In Germany some plants to-day have a sufficient mixer capacity to hold all the Sunday iron for direct conversion.

THE HUMAN ELEMENT.

To achieve uniformly good practice nothing is more essential than the building up of an intelligent, watchful and active furnace organization. The close co-operation of the foreman and the crew is needed to control efficiently every step in the operation. So much depends on correct discernment and quick action that an alert crew will in a day's work avert many troubles. Being continually in close contact with the furnace, they must be relied upon to watch the many little, yet important details of operation.

The furnace manager who fails to devote as much of his thought and energy to studying and improving his organization as he gives to correcting the design of his plant, misses one of his best opportunities. Any effort on his part to instill into his men a keener interest in the efficiency of the plant will make his task the easier. He should not hide his practice but should display the daily, weekly and monthly results in all their details, so that his men, from the constant observation of these, will derive a better understanding of their work and become more capable of doing it justice. By also giving them the opportunity to study rival plants, the incentive to greater effort is further stimulated. In no branch of industry is the exchange of experience more helpful and necessary to progress than in blast furnace work. And this method should be applied not alone to the management. Modern mechanical appliances have raised the standard of the men employed around a furnace; to keep their intellect alive and bent to their work is the command of economy and progress. Some of the best suggestions for improving operation and construction are obtained from the rank and file of the organization.

A crew convinced they are treated fairly and justly and that their employer takes an interest in their welfare, will

perform their duties willingly and cheerfully, and therefore efficiently. The welfare work now carried on by the steel industry is bearing abundant fruit. With the assistance of modern engineering and the safety campaign, it has not only succeeded in making the blast furnace plant, which in former days abounded in dangers, a safe and healthy place of work, but has exercised a most beneficial influence on the spirit and progressiveness of blast furnace organizations, especially where safety matters have been referred to the workmen themselves for suggestions and improvements of their own invention.

The betterment of the human element, which enters into every step of the process from the mining of the raw materials to the casting of the molten product, perhaps does not stand out as strikingly as the more apparent results achieved by modern engineering; yet great progress has in recent years been made in this direction, and the good results obtained in modern blast furnace practice are in no small measure due to the better spirit and greater intelligence of the workers.

OPPORTUNITY FOR PROGRESS.

In every art and industry the living generation, having reached a certain goal, is prone to believe that no further progress is possible. At the present time, with furnaces producing 500 tons and more daily from difficult ore mixtures, with fuel consumptions which we think closely approach the low limit, we may not see our way clear to further improvement; yet the possibilities are now as great as ever. Perhaps they lie in another direction, and we need not be discouraged if we fail to develop the 1,000-ton furnace or are unable to lower our past fuel records.

Our problem, I am convinced, is to reclaim and put to use those vast bodies of ore and coal which, owing to their adverse character, have in the past not been available for the manufacture of iron. This is by far our greatest task, a task which has the highest economic value in substantially contributing to our country's wealth.

The magnitude of the unit with which we deal, the large responsibilities involved, the long period of time which must elapse before new ideas are approved by practice or condemned, the many disappointments with which all of us have met, are bound to make us cautious and conservative. Yet in this age, where science and engineering have put at our command resources undreamed of by our predecessors, we will, I trust, in the daily drudgery of making pig iron, keep sight of our wonderful opportunities and do our share in advancing the blast furnace art.

MODERN AMERICAN BLAST FURNACE PRACTICE

JOHN N. REESE

General Superintendent Northern Furnaces, Republic Iron & Steel Company, Youngstown, Ohio.

Mr. Brassert has given the blast furnace fraternity considerable data and has opened up a number of new avenues of thought and investigation.

DISTRIBUTION OF RAW MATERIALS.

The proper distribution of the raw materials in the blast furnace has received the attention of blast furnace men of all time, but the problem cannot be said to have been fully solved even in this scientific age. If any proof of this assertion is needed, one has only to examine the patent office records or to make a list of the different kinds of distributing devices in use in this country and abroad. None of the various designs has proven its superiority over all others.

The ideal blast furnace top must:

(1) Be flexible, so that it can take care of any changes in the character of the materials charged and can be made to meet changing conditions of operation.

(2) Be simple and strong, so that it may be easily handled and may require little attention, and so that breakdowns may be few and easily repaired.

(3) Have a gas seal.

(4) Have a means of charging coke with the least possible breakage and abrasion.

(5) Give proper distribution of the raw materials on the large bell and at the furnace stock line.

Proper distribution is the placing of the ore, coke and limestone in the furnace so that the mass will have the same permeability to the ascending gases throughout all its sections and will descend smoothly and evenly to the hearth.

When these two essentials are assured the loss of carbon by direct reduction and by solution in the CO_2 of the gas will be at a minimum and good economical working will result.

There are many things outside of the distributing device itself that can render the distribution faulty.

Some of these influences are:

(1) Ore sticking to, and faulty balance of, the large bell.

(2) Side thrust, swinging and improper lowering of the large bell.

(3) Wearing of the stock line or change in the stock line due to the breaking or distortion of the protecting devices.

(4) Improper location of the downcomer openings, so that stock falls into them causing channels to form below each opening due to segregation of the lumps into columns.

(5) Downcomer openings too small in area or too few in number, causing the gas to channel and to carry off a large amount of fines into the downcomer.

(6) Carrying the stock line too far below the bell, making the size of the bell too large, and also causing unnecessary breakage of the coke and packing of the stock.

(7) Shifting of the furnace top relative to the furnace center, caused by warping, expansion or contraction.

(8) Warping and burning of the bell or hopper.

(9) Lack of care and watchfulness on the part of the operator.

(10) Bad weather conditions.

There are three types of blast furnace tops which are in more or less successful operation:

A. Stationary.
B. Revolving, at top of furnace.
C. Bucket revolved at bottom of furnace.

Stationary Tops.

The stationary top can be adapted to either the single or double skip. It usually consists of a receiving hopper, surmounting a cylindrical or elliptical throat with the bottom part drawn in and closed by a small bell. Considerable experimenting must be done to adapt the stationary top to

a certain set of conditions, if these conditions are materially changed the arrangement of the top must be modified accordingly. Overtravel and improper dumping of the skip affect distribution. If the central sleeve and rod are used to support the two bells there is a tendency for the fines to remain on the side beneath the skip.

The stationary top has the simplest mechanism, costs less to operate than other mechanical tops and has given successful results. A number of these tops are in use on large furnaces, but the newer furnaces show a marked tendency to adopt one of the other types.

Revolving Tops.

Revolving tops are of several kinds, differing principally in the method of discharging the materials upon the large bell. The four leading types are:

(1) Brown.
(2) Baker-Newman.
(3) Roberts.
(4) McKee.

The Brown top consists of a chute suspended to the receiving hopper, which is revolved about 86½° by the skip as it returns empty down the incline. The mouth of the chute is closed by a flap door as the large bell opens.

Experience with two of these tops on furnaces using entirely different raw materials has shown the following faults: The stock, as it slides through the chute, crowds the side opposite the skip. This occurs in a greater or less degree with every position of the top except when it points directly toward or away from the skip.

Several methods of removing this fault have been tried, such as dumping the skip very slowly, increasing the size of the charge, and narrowing the mouth of the chute; but none of them have overcome it.

The trouble may be stopped by causing the material to enter the chute centrally, by introducing a small bell and making a sort of combined Brown-McKee top, or by placing a receiving hopper with conical bottom between the skip and chute. This, however, increases the drop to which the coke is subjected.

The advantages of this type of top are its simplicity, lightness of construction and speed of operation.

The Baker-Newman top consists of a receiving hopper with a cylindrical throat closed by a small bell. A distributing or deflecting plate is attached to the bell rod. The bell and plate revolve about 87½° as they move upward and as the skip leaves the top of the furnace. As the top is usually operated the bell and plate are down when the skip dumps its load.

With this top there is less tendency for unequal distribution or separation of lumps from fines. If anything happens to the revolving mechanism of either, however, the furnace must be stopped until repairs are made or filling on one side must be resorted to. Both have the advantage of allowing coke, sand or scrap to be filled at certain points if necessary.

Some objections have been raised to the placing of the stock in piles on the large bell instead of in an even ring.

The McKee top consists of a receiving hopper, a cylindrical or slightly conical throat closed by a small bell. In some of these tops an inverted conical apron is introduced below the small bell, which throws the stock towards the apex of the large bell.

The method of operation is not the same at all plants, the difference being mainly in the number of skips dumped at certain points of distribution and in the number of points.

Revolving Bucket Device.

The Neeland or Duquesne top consists of a cylindrical bucket narrowed at the bottom by a conical section and closed by a small bell. The larry car dumps directly into the bucket, which is revolved to bring the high side of the load on the quarters. It is then hoisted to the top of the furnace where the bucket seats on the gas seal and dumps its contents onto the large bell.

Some trouble has been experienced at several plants with the small bell that closed the gas seal so that a slide has been introduced. The advantage of this slide is that

it leaves the seal entirely free for the lowering of the small bell and prevents the bell lever cutting the stock.

The Neeland device removes the revolving mechanism from the top of the furnace, allows the distribution in each bucket to be inspected, and if anything happens to the revolving machinery fairly good filling can be accomplished by leveling the contents of the bucket by hand while repairs are being made.

A number of other devices have been patented and several have been installed but those described have withstood the test of time and are in more or less successful operation.

The following table gives a census of the different tops used in the Mahoning and Shenango Valleys at the present time:

Hand Filled	16
Stationary	10
Neeland	7
Brown	4
McKee	4
Kennedy Revolving	1

The newer installations have been equipped with the Neeland top.

At several plants other types of distributors or deflectors have been installed. I refer to the Killeen and McDonald distributors.

The Killeen distributor consists of a stationary apron hung below the hopper between the inwall and the large bell The stock strikes the apron causing the fines to be deposited in an annular ring below it while the lumps form a ring next the wall and a column in the center.

The McDonald distributor produces the same result and differs from the Killeen only in that the apron can be raised or lowered as desired and the fines placed near the walls or in an annular ring below the apron. It is claimed that the walls can be kept clean by the use of these distributors.

Advantage of Single Large Bell.

The single large bell still remains the favorite with the vast majority of blast furnace managers. The present tend-

ency is to have a rather large bell, especially for fine ores, depositing the fines close to the walls and allowing the lumps to rebound and roll, forming a comparatively loose column in the center.

The proper size of bell for a given stock line diameter has been worked out from long experience with Lake ores, but there is still some difference of opinion. The rule was to allow an annular space of about two feet between the bell and the stock line, but a later rule is to make the bell so that the square of its diameter is equal to or slightly greater than one half the square of the stock line diameter.

The reason for the better results with the large bell in charging fine ores are:

(1) Owing to the comparative smoothness of the brick-work and the loosening effect of the friction between the stock and the wall, the gases have a tendency to follow the walls. Placing the fines close to the walls counteracts this.

(2) The stock in the center of the furnace travels faster than along the walls due to the friction against the bricks and the resistance resulting from the narrowing of the bosh walls, as well as on account of the loose nature of the materials in the central column. So there is a tendency for the fines to work from the walls into the interstices in the central column. This causes the mass to become more nearly of the same permeability throughout and therefore, aids the the proper distribution of the gases.

The distance below the bell that the stock line is carried has a direct bearing upon the distribution. The greater the distance, within a certain limit, the greater the tendency to deposit the fines toward the walls. The bad effect of too small a bell can sometimes be overcome by dropping the stock line a short distance.

Stock line protection is a vital part of good distribution, because wearing of the walls at the stock line or warping of a protecting device can upset the distribution of the best possible top.

MODERN AMERICAN BLAST FURNACE PRACTICE

Arthur J. Boynton

Superintendent, Blast Furnaces, The National Tube Company, Lorain, Ohio.

In the paper which Mr. Brassert has just read he has given us a very complete and correct idea of the requirements for the successful manufacture of pig iron, and has stated that increased efficiency is the problem of to-day. During the past few years a very prominent part of the effort toward greater efficiency at the steel works furnaces with whose practice I am familiar, has been in the attempted use of acid slags and higher blast temperatures. These two features of practice are related, not merely because the one cannot be used to the fullest extent without the other, but also because they increase the fuel efficiency of the furnace in the same way, the hot blast by increasing the combustion temperature of the gases in the furnace, and the acid slag by decreasing the temperature necessary for the operations of the hearth. The advantage of hot blast is not altogether and perhaps not chiefly in the heat which it carries into the furnace but in the combustion temperature which it produces. That the effect of the increase in the difference between combustion temperature of gases and melting point of slag is much greater than that due to the amount of heat carried in by the blast has been clearly pointed out as a reason for the effectiveness of both hot blast and dry blast. Similarly the economy of acid slags is not determined entirely by the quantity of heat required to melt the slag but also by the temperature of melting.

Increase in coke consumption and the corresponding decrease in tonnage does not, however, by any means represent the sum total of the disadvantages of running with a basic slag. Such a slag carries too little silica to absorb the lime present in the region of the top of the bosh. The

lime is consequently rejected by the slag at this point and some of it remains as the chief cause of scaffolds on the bosh. The serious consequences of the formation of these scaffolds are well understood, and include irregular iron, excessive production of flue dust and interrupted operation.

Practice With Acid Slags and High Heats.

The requirements for the use of acid slags and high blast temperature are not easily fulfilled. They include correct furnace lines, uniformity of raw materials, since the furnace heavily burdened and running on an acid slag is extremely sensitive to variations in the charge, low sulphur content in the coke, correct distribution, and stove equipment to generate the temperature required. It is seldom that all of these requirements are fulfilled. Consequently, in many cases where the use of acid slags and high heats has been attempted, no consistent increase in burden was possible, and the results have been chiefly noticeable in iron alternately too hot and too cold, and in the presence of scouring slags, together with an undue wearing of the lining through the elevation of the temperature at any given level inside the furnace.

Mr. Brassert has spoken in detail of the development of furnace lines and the necessity of uniformity in raw materials and has also stated that the volume and basicity of slags are generally determined by the duty of sulphur elimination. The ability of any slag to remove sulphur at any given hearth temperature depends on its basicity, which is generally taken to be the ratio between the sum of the lime and magnesia and the silica. Any attempt to classify the sulphur holding ability of the slag in accordance with the sum of the silica and alumina is likely to show confusing results where there is much variation in the alumina.

A comparison of Bessemer slags made at Lorain, covering 120 furnace months, shows a gradual increase in sulphur content as the basicity increases. The most acid slag carries 1.64 per cent. sulphur, and the most basic over 2 per cent. The slags range from 37 per cent. to 32½ per cent. silica, and from 1.2 to 1.5 ratio of bases to silica. The

unit taken is the average composition of the slag from one furnace for one month.

TABLE SHOWING SULPHUR CAPACITIES OF BESSEMER SLAGS.

Furnace Months	SiO_2	Al_2O_3	Sulphur	Ratio of Bases to Silica
20	37.07	13.57	1.64	120 to 125
16	36.45	13.16	1.67	126 to 130
22	35.07	14.02	1.83	131 to 135
18	34.33	14.12	1.90	136 to 140
28	33.50	14.13	1.96	141 to 145
15	32.38	15.07	2.03	146 to 150

The advantage of running on the more acid slag is indicated by the coke practice corresponding to these averages, the average coke consumption for 20 months with the most acid slag being 1,922 lbs. per ton and for 15 months with the most basic slag 2,269 lbs. per ton.

LIMITATIONS IMPOSED BY SULPHUR IN THE COKE.

Where a consistent removal of sulphur is specified, few of our blast furnace plants have been in a position to avail themselves of the advantage of acid slag on account of the amount of sulphur in the charge, almost all of which is contained in the coke. With an ore supply containing 7½ per cent. silica and 2,000 lbs. of average Connellsville coke the normal slag volume is a little over 900 lbs. per ton of iron. With an acid slag capable of carrying not over 1.64 per cent. sulphur at the hearth temperature when on Bessemer iron, the limit of sulphur in the coke for the normal slag volume is .8 per cent.

At the hearth temperature of a furnace making basic pig iron, with the same kind of slag, where the silicon is determined by the hearth temperature, the sulphur content of the slag will be about 1.2 per cent. This sulphur capacity in the slag requires sulphur in the coke below 0.6 per cent. for the normal slag volume. Any increase in sulphur in the coke above these points must be met in one of two ways, either by increasing the basicity of the slag or by increasing its volume.

With a sulphur in the coke of 1 per cent. the additional

slag would be 300 lbs. in Bessemer practice and 700 lbs. in basic. A voluntary increase in slag volume to the amount of this latter figure would probably be considered very poor practice. The additional cost for the three principal items of increased coke, increased limestone and increased operating cost due to lessened tonnage would amount to about sixty-seven cents per ton of iron, all of which can be more or less accurately calculated; while the losses due to running on basic slags cannot be calculated with any certainty. The fact that the blast furnace man is required to choose between these evils emphasizes the importance of determining the cost of coal washing and its application wherever practicable, as well as the maintenance of a constant sulphur content in any grade of coke by a local grading similar in principle to that used in the case of ores.

Distribution of the Charge on the Bell.

Aside from furnace lines and quality of raw materials, nothing has greater effect on the ability to carry heavy burden than the distribution of the charge on the bell.

Some years ago we made, at Lorain, a series of experiments continuing over some months, first with small models and afterwards on the full scale. These experiments showed the extreme difficulty of obtaining in a skip-filled top, with materials differing from each other as widely as coke and stone differ from ore, a distribution which is correct by weight and also with respect to proportion of coarse and fine material on each quarter of the bell.

Mr. Brassert, in his paper, has clearly stated the importance of an equal subjection of all parts of the charge to the action of the furnace gas as a matter of fuel economy. That more or less direct reduction takes place as a result of relatively greater compactness of the charge on one side of the furnace is unquestionable. Even where high blast heat can be applied to remedying this condition, it is still to some extent a waste of the hot blast,—applying it to do work in the hearth which should have been done above. In many cases a limiting condition to the use of hot blast is found in this cause, inasmuch as a furnace with even slightly im-

proper distribution reaches the limit of burden on one side only. Bad distribution is also a very frequent cause of excessive production of flue dust, a condition for low production of which is the continuous and uniform movement of the charge practically as one mass. Experience has shown that with such a movement a relatively slight production of flue dust takes place, and that it is not the average velocity of gases in the top but the excessive velocity due to slips which throws over the dust. The margin of velocity, however, is so slight that even very slight slipping will greatly increase the dust production. Uniform movement of the charge can only take place with perfect stock distribution. Any other distribution will result in a movement which may be steady on one side and intermittent on the opposite side, resulting in more or less of a vertical shearing of the charge which is a most usual cause of excessive flue dust.

The fact that good practice under favorable conditions has been made with a distribution that is not perfect is not, in my judgment, a good reason for neglecting the utmost possible refinement in distributing the charge. This refinement should include, in the case of skip-filled furnaces, the experimental determination of the best possible proportions of receiving hopper and throat, and of the position, angle and speed of dumping of the skip car; the removal of all obstructions to the flow of stock, such as crossheads for supporting the main bell, and lifting and holding lugs cast on its surface; a sufficient slope, probably not less than 50° for the main bell, and the machining of its entire surface; the absolute centering and alignment of every part of the charging machinery with the furnace; the governing of extent and speed of travel of the bells, and the rotation of the charge in the throat. With regard to this last feature it should be noted that, even though it is possible under any carefully observed set of conditions to effect a perfect distribution in a stationary top, the conditions of operation, including variation in the proportion of coarse and fine material in the coke and limestone, and of the water in the ore, together with the practical impossibility of maintain-

ing the angle and speed of dumping constant at all times, will result in an error which we cannot afford to overlook. The rotation of the charge is by no means a cure-all for imperfect distribution, but it seems to me to be essential to the high degree of refinement which is necessary for the best possible practice.

The advantages of running with a high blast temperature when the establishment of the conditions referred to above has made its use easy and natural, are well understood and generally admitted. In saying this I have in mind not so much the use of excessively high temperatures as a general increase in the temperatures now in use, which average between 900° and 1,000°. However, the prospect of working with leaner ores and higher slag volumes makes it seem probable that an increase beyond the highest temperatures now regularly used may be expected, since it is generally true that in districts where lean ores have to be smelted, the average blast temperature is much higher than it has been in the district using Lake ores. The question of stove capacity and design is, therefore, of much interest.

Stove Capacity.

The average stove capacity of our furnaces 21′ 6″ and over in bosh diameter is about 175,000 sq. ft. of heating surface, distributed in almost every case among four stoves. These stoves are generally of the two pass side combustion or three pass type. The consideration which has governed the size of these stoves has been primarily ability to get the temperature desired, seldom over 1,200°, even for short periods of time. The details have been governed largely by considerations of structural strength and facility of cleaning. Most of the two pass stoves are built with nine inch checker openings and three inch walls. The three pass stoves generally have four inch walls and an average size of checkers not less than those of the two pass stoves. Aside from the question of cleaning, and with the object of gaining as large heating surface as possible inside a given shell, the thickness of the checker walls should be as small as strength will permit, and the openings the same diameter

as the checkers. With three inch walls, a reduction in the diameter of the openings from nine inches to six inches will increase the surface about eighteen per cent., and a reduction to four inches about thirty per cent. With a two and one-half inch wall and four inch openings the increase in surface is over 51 per cent. By changing their size it is therefore possible where washed gas is available to make a very considerable increase in the capacity of the stove without increasing the radiating surface of the shell, and this fact forms one of the strongest arguments for the use of washed gas. With unwashed gas the percentage of increase of surface which it is practicable to make is relatively small, since six inches in diameter of opening is generally considered the smallest advisable.

TABLE SHOWING SURFACE PER CU. FT. VOLUME AND BRICK PER CU. FT. VOLUME IN VARIOUS SIZES OF CHECKERS.

Thickness of Wall	Diameter Opening	Surface in Sq. Ft. per Cu. Ft. of Volume	Per Cent. Increase	Cu. Ft. Brick per Cu. Ft. Volume	Per Cent. Increase
3 in.	9 in.	3.000	....	.438	..
3 in.	6 in.	3.556	18.5	.556	27
3 in.	4½ in.	3.840	28.0	.644	47
3 in.	4 in.	3.918	30.6	.674	54
2½ in.	4 in.	4.544	51.5	.621	42

Aside from increase in surface there are other advantages of small checkers, due to the changed ratios of surface to volume, which result in much greater intimacy of contact between the air or gas and the brick work, and a much better economy in a stove of any given height.

TABLE SHOWING RATIOS OF SURFACE TO VOLUME IN SQUARE CHECKERS OF DIFFERENT SIZES.

Diameter of Square Checker Openings	Height of Checker	Surface Sq. Ft.	Volume in Checker Cu. Ft.	Ratio of Surface in Sq. Ft. to Volume in Cu. Ft.
3 in.	1 ft.	1,000	0.0625	18 to 1
4 in.	1 ft.	1,333	0.1109	12 to 1
4½ in.	1 ft.	1,500	0.1409	10.67 to 1
6 in.	1 ft.	2,000	0.2500	8 to 1
9 in.	1 ft.	3,000	0.5625	5.33 to 1

From this table it appears that the surface in contact with any volume of gas or air varies inversely as the diameter of the checker opening.

From the relations shown it is evident that in a pass of a given length, the surface to which any given amount of air or gas is exposed in traveling through the pass at a given speed is also inversely proportional to the diameter of the checker opening.

It follows that in order to get the same relation between surface and volume in a nine inch checker as in a four and one-half inch checker it is necessary to reduce the speed of the gas or air one-half, or double the height of the stove.

The method of increasing the stove capacity will vary at each plant in accordance with the size of existing stoves, the final determination of minimum dimensions in the checkers and the number of square feet required. A lower limit of three inches in the thickness of the checker walls and four inches in diameter of opening will barely enable the small 21′ x 100′ two pass stoves to reach the present capacity of the larger three pass stoves, four of which run a little below 200,000 sq. ft., and any increase above this figure will require additional height or a fifth stove. The capacity of the 22′ x 100′ three pass stoves can be increased over 30 per cent. by the use of three inch walls and smaller openings.

A recent description of a German method of forcing the air for combustion of gas into the stoves, and the consequent ability to run the furnace with two stoves, one on air and one on gas, has attracted some attention in this country. Comparison shows, however, that the four stoves in question which were operating on a furnace making 168 tons of iron per day were as large as the stoves of some American furnaces making 500 tons per day, and that with only half this equipment in use the square feet of heating surface per ton per day, and probably per volume of air blown remains greater than is the case at most American furnaces. The so-called "forcing" is, therefore, not forcing according to our standards.

In conclusion it may be said that successful blast furnace

practice is well known to consist in the proper adjustmen to each other of a great number of details, none of which is too small to have a bearing on the general result. Our technical literature of the blast furnace is largely made up of studies of separate details, each considered more or less by itself. The completeness with which these details have been enumerated and their relations to each other described, is a peculiar and valuable feature of Mr. Brassert's contribution of to-day.

MODERN AMERICAN BLAST FURNACE PRACTICE

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Mr. Brassert's statement that, "with more and more difficult raw materials, progress is not so much in the direction of new records of production and fuel consumption, as in the ability to maintain the best results of the past in the face of greater handicaps," has particular application to the progress made during the last six years in developing the practice of smelting the high alumina Cuban ores in the blast furnace. The fundamental conditions have been somewhat different as to progress made in Mesaba, compared with that made in Cuban ore, practice. In the latter case, it has not been a struggle to retain ground already conquered. It has rather been one of aspiring to the high standards previously set by Mesaba practice. During the entire period, the Cuban ore furnaceman has been on the under side. He has been fighting to do as good work on these ores, which in their natural condition might be termed low grade, as had previously been done on Lake ores, without ever daring to think that he could surpass the results obtained in earlier practice. All the odds seemed against him.

PROGRESS IN DEVELOPING THE SMELTING OF MAYARI ORE.

Before proceeding with a more or less detailed account of the various steps in the march toward the present very satisfactory results in smelting Mayari ore, it might be interesting to picture the obstacles, some apparent and some not, which lay in the path of the metallurgist and engineer, when the Mayari ore fields were discovered in 1904.

The deposit was enormous in extent, but it was located some two thousand feet above sea level on a plateau diffi-

cult of access, miles from the sea coast, and hundreds of miles from the blast furnaces which were to be supplied, in an almost uninhabited, insect and fever infested, district. The problem of mining was simple, but the ore contained great quantities of moisture and combined water, which necessitated drying before shipment to the States.

Nodulizing Problems.

To erect and operate an industrial plant with all the requisite accessories for this purpose in a country far from the labor and manufacturing markets was not an inviting task; yet in view of the freight saving obtainable by eliminating the water in the ore, this seemed to be the only recourse. The ore was extremely fine, and naturally, since nodulizing was but one step beyond drying, there seemed no reason why the two results could not be obtained in a single operation. This opened the immense field of nodulizing problems. Due to excessive moisture and, no doubt, partly to the high alumina content, Mayari ore was not as easily nodulized as other materials, such as Cornwall concentrates, pyrite cinder, flue dust, etc., upon which much experience had previously been gained. Preliminary experiments were conducted with Mayari ore in a nodulizing kiln at the Lebanon Plant of the Pennsylvania Steel Company. These experiments indicated that there was no apparent difficulty in forming nodules, nor was the fuel consumption excessive. However, when the somewhat larger kilns, designed for greater capacities, were placed in operation at Felton, Cuba, with the best labor available, which was none too good, it was discovered that there were many lessons yet to be learned. Extensive mechanical changes were necessitated to adapt the plant to tropical conditions. Machinery which was at all complicated, or which required intelligence in operation had to be eliminated as far as possible, for the Cuban and imported labor proved quite unreliable.

Besides this, Mayari ore in the raw state was handled with great difficulty, due to its sticky, clayey consistency, and the original bucket elevators and conveyors gave way

to gantry cranes and grab buckets. In the raw state, the ore would stand in a pile at a ninety degree angle, and even when grab buckets were installed, the question of handling was not entirely solved. This physical condition of the raw ore gave no end of trouble in obtaining regular feed to the kilns. Various constant feed devices were tried, until the present revolving platform feed was determined upon as the best to meet the conditions. Had the plant been located within easy reach of a manufacturing center, all of these difficulties could have been corrected within a short time and at fairly small expense, but since it was necessary to build all machinery in the States and ship it to Cuba, months were consumed, where under similar conditions in industrial plants more favorably located, it would have been a matter of days.

From the first, in nodulizing Mayari ore the fuel consumption and the quality of nodules, as far as fines were concerned, caused considerable disappointment, although it was expected that slightly more fuel would be needed than experience with other materials had established. The question of obtaining complete combustion, together with that of transmitting most effectively to the ore the heat generated; the diminution of heat losses; the recovery of lost heat; experiments to facilitate nodulizing and increase the size of nodules by additions of foreign substances, by reducing the melting point, and otherwise—all these constitute but a few of the items which have been consuming the time and thought of the metallurgist.

Concerning the quality of nodules produced, it was assumed at an early date that 90 per cent. remaining on a 40 mesh screen would be satisfactory for blast furnace use. This size was assumed on the basis of Lake practice, the idea being to get ore somewhat coarser than the Mesaba ores. With this standard set, operations at the Felton plant were brought to a fairly satisfactory basis. Kiln tonnages were increased gradually to a maximum of nine tons per hour and at the same time fuel consumption was reduced. However, the quality of ore produced gave excessive flue dust losses in the blast furnace, and it was found

necessary to make a new standard of 75 per cent. material remaining on a 10 mesh screen. This more recent standard resulted in reducing the kiln tonnages and increasing the fuel consumption, but by using binders in the nodulizing process satisfactory results were obtained. Since successful blast furnace practice demands the coarser nodules, future advances in Cuba will be made upon this basis.

Blast Furnace Problems.

Following the nodulizing problems came those of the blast furnace. Uncertainty centered about the behavior of a furnace carrying such high percentages of alumina in the slag. There was no precedent to guide the furnaceman and naturally he had to be extremely cautious. In September and October, 1904, experiments were conducted on a small furnace at the Steelton plant of the Pennsylvania Steel Company to determine some facts concerning this important question. By means of Lake ore, chromite, brick bats, and bauxite, a furnace mixture was concocted approximating Mayari ore in chemical composition. The test run lasted 11 days, during which time the furnace averaged 102 tons on a one to one fuel ratio. This mixture worked with sufficient success as to the character of the slag and the general furnace conditions, to warrant a small shipment of ore from the Mayari district. About 1,200 tons were transported on mule back from the deposit at El Perio to the sea coast, and shipped to Steelton, where it was tried with more or less success on No. 1 Furnace in February, 1906. This test was of six days' duration, the furnace averaging 59.5 tons of iron per day on a fuel ratio of 2.13. The flue dust was excessive, however, and as a result the actual yield of pig iron was but 29 per cent.

Notwithstanding the unfavorable results as to fuel ratio and yield, the fact was established that the alumina content of the ore presented no insurmountable difficulties, but it was conceded that the physical condition of the ore would require considerable attention. Further shipments of raw ore, and later nodules, were made to the States and converted into iron from which the steel maker had an oppor-

tunity to test his skill in the elimination of chromium. Suffice it to say that the troubles of the open hearth and Bessemer man were many, but this phase of the Mayari problem was worked out economically far in advance of the blast furnace difficulties.

Unlike the conditions which surrounded the development of Mesaba practice, experimentation on the Mayari ores was confined to the resources and equipment of one company, and was conducted with the use of coke, generally speaking, of an inferior quality and with a limited corps of furnace operators. With but two plants available for experimentation, and these not equipped for handling such varied conditions while conducting their routine business, progress was naturally slow. Problems had to be solved one by one, and at such time as not to interfere with the regular output of iron and steel.

Peculiar Characteristics of Mayari Ore.

Before proceeding further, it might be well to describe in a general way this ore which has recently become such an important addition to the iron ore resources available to the steel industry of the eastern United States. The enormous deposits in northeastern Cuba can be mined at a cost which can be duplicated elsewhere only under exceptional circumstances. The heavy mantel of Bessemer grade ore, ranging in thickness from one foot to eighty feet and averaging about eighteen feet, with absolutely no over burden, covers a plateau of serpentine bed rock. From this it originated through a process of rock-disintegration and decay.

As mined, Mayari ore has approximately the following chemical composition:

Fe.	H_2O	SiO_2	Al_2O_3	Mn.	P.	S.	Cr.	Ni.	Combined water
38.14	23.22	2.00	10.00	.51	.013	.15	1.46	.57	11.50

It consists of a mixture of hydrated iron oxide, limonite, with hydrated aluminum oxide, bauxite, and the oxides of nickel, chromium, and cobalt. In appearance the ore is a reddish yellow to dark red in color, and is of a decidedly clayey consistency.

The following table gives the results of a sizing test made on the raw ore after it had been thoroughly dried. This will indicate the extreme fineness of the ore. For comparison, I have placed beside this the screen test of Mesaba ore which Mr. Brassert gives in his paper.

Ores	Screens							
	No. 2	No. 8	No. 20	No. 40	No. 60	No. 80	No. 100	Through 100
Mesaba......	25.40	26.86	12.54	10.86	6.92	2.76	3.34	11.33
Mayari (Raw)	0.00	27.72	34.36	18.93	6.03	4.07	1.05	7.84

Pretreatment of the Ore Necessary.

It is true that experience with Mesaba ores served as a precedent and demonstrated that it was possible to smelt very fine ores economically in a blast furnace, but perhaps this fact misled rather than guided those who were working to solve the mysteries of Mayari ore. As a consequence, much valuable time was wasted in trying to make a furnace digest the raw ore with its 20 to 25 per cent. hygroscopic moisture and 11 to 13 per cent. combined water. However, to counteract this tendency, the desire to save freight charges on shipments of useless water from Cuba to the States immediately suggested the use of some type of dryer. Then too, although furnaces were operated on high percentages of the raw ore, the excessive losses of iron-bearing material as flue dust, the consequent low yield of iron and nickel, and the uneven working of the furnace caused by slips and explosions, made the process uneconomical and indicated at an early stage that some method of preliminary treatment must be resorted to in order to agglomerate the ore and make it suitable for the blast furnace.

With large percentages of raw Mayari ore in a furnace mixture, violent slips occurred and made operations extremely irregular. Why this ore should act worse than Mesaba ores in this respect in passing through the furnace has been a question to which furnacemen have given a great deal of thought. Perhaps the most logical explanation is that the 11 to 13 per cent. of combined water caused the trouble. No doubt, following a period during which the

furnace was hanging, the stock was precipitated into the lower zones where the temperature was high enough to drive off the combined water. The sudden generation of steam caused an explosion which gave the typical fine ore slip. These did considerable damage to the old fashioned open top furnaces used on this work, both at Sparrow's Point and at Steelton, especially at the former plant, where more experimenting was done on the larger capacity furnaces.

Nodulizing.—Considerable preliminary experimenting was done to determine the most feasible means of preparing the ore. The use of briquetted raw ore lost favor, chiefly on account of mechanical difficulties and cost of production. A machine was built for the purpose of rolling the ore into corrugated sheets which were afterwards sintered. This likewise proved expensive and did not answer the purpose. Finally, nodulizing was determined upon as the most promising method, and the erection of a plant was begun in Cuba. The fact that the Pennsylvania Steel Company already had nodulizing kilns in successful operation at Steelton and Lebanon on Cornwall concentrates, pyrite cinder, flue dust, etc., no doubt led to the use of the kiln.

The first kiln went into commission November, 1909, and the first shipment of nodules was made in December of that year. At present, the plant consists of twelve kilns; eleven, with 10 feet shell diameter by 125 feet long, and one, 9 feet shell diameter by 125 feet long, with a daily capacity of 1,500 to 2,000 tons of nodules. Numerous modifications of this process have been developed which show good results. The analysis of the nodulized Mayari ore dried at 212° is as follows:

Fe.	H_2O	SiO_2	Al_2O_3	Mn.	P.	Cr.	Ni.	S.
56.53	2.14	4.11	12.89	.71	.018	2.04	.93	...

The following table gives a comparison of screen tests made on Mayari nodules produced in Cuba on the old basis: (1) 10 per cent. through the 40 mesh; (2) coarse nodules produced in Cuba; (3) lime nodules which come up to the

new standard of 75 per cent. on the 10 mesh; and (4 and 5) typical Lake ores as shown by Mr. Brassert.

	On ¾ inch	No. 2	No. 8	No. 20	No. 40	No. 60	No. 80	No. 100	Through 100
(1) Fine Mayari Nodules.......	4.70	2.40	31.80	25.50	21.53	6.76	2.95	1.16	3.20
(2) Coarse Mayari Nodules......	8.75	4.15	44.42	22.34	13.31	3.45	1.46	.49	1.63
(3) Coarse Lime Mayari Nodules.	28.45	10.98	41.15	11.75	5.35	1.02	.43	.10	.77
(4) Mesaba ore.....	.....	25.40	26.86	12.54	10.86	6.92	2.76	3.34	11.33
(5) Old Range ore..	.....	30.16	30.76	15.01	8.14	4.16	2.06	2.74	7.01

NOTE—For comparative purposes, on account of the use of a different screen scale, the 10 mesh screen used in our tests is counted as No. 8 as used by Mr. Brassert.

Using the nodules as shown in test No. 1 in a 300-ton furnace with 75 per cent. in the mixture, 10 to 20 per cent. of flue dust was made. With 75 per cent. of coarse nodules in the mixture in such a furnace, the flue dust should drop to 5 per cent.

The question immediately arises as to why the flue dust loss with fine Mayari nodules is so much greater than with the relatively finer Lake ores. This is probably to be explained by the fact that the nodule particles are more free and granular than in the Lake ores and no doubt retain this condition to a greater depth in the furnace due to the absence of any great amount of carbon deposit in the upper zones of the furnace. Laboratory experiments, made by passing blast furnace gas over samples of Mayari nodules and "Admiral" Lake ore under identical conditions of temperature, showed maximum carbon deposit of 157 per cent. at 450° C. with "Admiral" ore against a maximum carbon deposit of 0.7 per cent. at the same temperature with Mayari nodules. This condition is perhaps somewhat modified in the blast furnace, yet it is possible that it affects the tendency of the two ores to pass off in the gas as flue dust.

Sintering.—A considerable tonnage of Mayari ore in the natural state has been sintered in Greenawalt pans by ad-

mixture of furnace flue dust which furnished the combustible material, but up to the present time, the sintering of this ore with the addition of coal, coke, or other fuel has been conducted only on an experimental basis. Mixtures of anywhere from one-quarter flue dust (15 to 18 per cent. carbon), with three-quarters raw ore, down to three-quarters flue dust with one-quarter raw ore have given good results. Eight to ten per cent. of fine anthracite coal, culm or coke breeze mixed with the ore gave a good sinter when tried experimentally. Bituminous coal did not work satisfactorily as the hydro-carbons, tar, etc., volatilized from the coal in the burning portion of the charge condensed in the pores of the cold and wet portions, thereby closing up the air passages and causing dead unsintered spots. The sintering process promises to prove the most efficient means of preparing Mayari ore for the furnace.

Briquetting.—Attention has been paid to application of the Mashek briquetting machine to the treatment of raw Mayari ore. This machine in its present form consists essentially of two corrugated rolls, with the corrugations running parallel to the axis of the rolls, on the surface. These rolls are held together by powerful springs which exert pressure on the ore as it is fed between them. Pencils of compressed ore approximately twelve inches long and one and one-half inches in diameter result, and it is hoped that these will hold together till they pass down into the furnace, or if they do break, will not produce fines. Of course, this material will not stand weathering and consequently will have to be charged directly from the machine into the furnace. Since the cost of mining of Mayari ore is so exceedingly low, any means by which the ore may be successfully prepared for use in its natural state is sure to prove attractive. It may be found that the ore in its natural condition is best suited for reduction in a blast furnace.

Coke Conditions.

To my mind, the inférior coke heretofore available in carrying on the furnace operations has been the greatest stumbling block in the way of satisfactory progress, equal-

ling in importance the question of the size of nodules. The Maryland Steel Company was forced to use in its furnaces coke from an obsolete by-product coke plant—one of the first of its kind built in this country.

At Steelton, coke oven operating conditions were all that could be expected with a modern Semet-Solvay coke plant, but the character of the coal supplied to the ovens resulted in a coke of varying ash and sulphur content. The physical structure was weakened by layers of slate forming fracture planes, and this resulted in excessive quantities of coke breeze.

As a consequence of the use of raw coke and coke containing worthless breeze, exceedingly high blast pressures resulted. Coke dirt scaffolds formed, and then at intervals would slide in great masses into the furnace hearth. The furnace required continual checking to prevent heavy slips. When the already fine state of the stock column due to the coke, was further aggravated by the use of fine Mayari nodules, the furnace conditions grew worse. Under the circumstances, it was perhaps only natural that an undue share of the furnace troubles was attributed to Mayari ore. In other words, the extremely fine condition of the stock column due to both fine dirty coke and fine Mayari nodules has been the cause of high pressures, loss of tonnage, increased fuel consumption and practically all the other bad effects which were experienced on high percentage Mayari mixtures.

Certain developments of the last few months have cleared the horizon both at Sparrow's Point and at Steelton. Due to business conditions, all furnace operations were suspended at the former plant in January, 1914, and at that time also the old coke plant passed out, and has been dismantled. Operations were resumed in March, using a high grade Connellsville coke. Since then, normal pressures, exceptionally good fuel consumption and tonnage, and ideal furnace operations have been the rule.

Following are some records of No. 2 furnace, Maryland Steel Company, under both conditions—with old by-product coke and with Connellsville coke:

	Old Coke			Connellsville Coke		
	Sept. 1913	Oct. 1913	Nov. 1913	Mar. 1914	April 1914	May (14 days) 1914
Average daily tonnage...	316	329	302	337	427	436
Average daily fuel ratio.	1.18	1.14	1.13	1.22	1.01	0.98

Much of the good record of April and May, 1914, is no doubt attributable to the use of coarser nodules than had previously been used. That the size of the nodules is an item of great importance is borne out by practice on 100 per cent. nodulized Cornwall concentrates at Lebanon. On this ore, of a character entirely different from Mayari, it is an established rule that fine nodules result in retarding the traveling of the furnace, in abnormal blast pressures and in reduced outputs of iron.

During this same period, at Steelton, a coal washing plant was completed for the purpose of removing slate and sulphur from the coking coal. This plant began operations in March, 1914, and at once the resulting quality of coal was such as to give an excellent coke in the ovens. The washing plant has a capacity of approximately 1,500 tons of washed coal in ten hours. The analysis of the Penn-Mary coals, coke from unwashed coal, washed coal, and coke from washed coal are as follows:

	Volatile	Fixed Carbon	Ash	Sulphur
Penn-Mary Coals..............	25.00	65.63	9.37	1.80
Coke from unwashed coal......	1.29	86.07	12.64	1.33
Washed coal..................	27.51	66.17	6.32	0.96
Coke from washed coal........	0.89	90.35	8.76	0.86

The coke resulting from washed coal was of an exceptional character, physically as well as chemically, being strong and tough, with a splendid open cell structure. The results of some physical tests made on washed and unwashed coke, showing a slight decrease in specific gravity and a correspondingly slight increase in the size of cells, due to washing coal, were as follows:

	Unwashed Coke	Washed Coke
Specific gravity, apparent......	.972	.935
Specific gravity, real...........	1.812	1.798
Per cent. cells.............	46.96	48.31
Per cent. walls............	53.04	51.69

The Penn-Mary coals are naturally good coking coals and make splendid coke when sulphur and ash are within reasonable bounds. This is no doubt the reason that such a slight difference is noted between the washed and unwashed coals.

Limestone.

A local dolomitic limestone, which for Lake ore practice would be considered of a very low grade, suits the Mayari practice splendidly at Steelton. It analyzes approximately 3.5 to 6 per cent. SiO_2, 69.5 per cent. $CaCO_3$, and 25 per cent. $MgCO_3$. In Cuban ore practice it has been found that 9 to 10 per cent. MgO in the slag is very beneficial. At Sparrow's Point a mixture of half calcite and half dolomite is used to obtain this condition. When calcite alone was used, trouble was experienced with foamy cinder and heavy slag runners. All stone is crushed to go through a six-inch ring, and the fines removed.

The Latest Experiments in Practice.

With ideal coke available, and with a new standard established for the coarseness of Mayari nodules, a splendid opportunity presented itself for the solution of some unsolved problems. By eliminating so far as possible all the variables the field was opened for the study of slag conditions, the internal working of the furnace and other items which might be demonstrated. With this object in view, an elaborate series of tests was begun in March, 1914, on No. 1 furnace at Steelton.

To be sure, this furnace is small, being 9 feet 6 inches hearth, 15 feet bosh, 11 feet stockline, 65 feet high, yet for experimental work it presented decided advantages. Tests of longer duration could be run on smaller tonnages of materials, and since most of the ore was especially prepared, this was quite a considerable item. It might be argued that results attained on this small furnace would not be comparable with those to be expected on a larger furnace. To meet this argument, we have previous history giving the comparative performance of this small furnace and larger

ones on other mixtures with conditions approximately alike. From earlier experience, it is fair to assume that this small furnace will run from 200 to 250 pounds higher on fuel consumption than one of the 300 ton furnaces. This is due chiefly to small size and uneconomical lines, and partly to the fact that the output is limited by lack of stove capacity and by the antiquated methods of filling. On the other hand, the flue dust production would be but half that of a 300-ton furnace.

After the blowing in on March 16, 1914, the furnace became fairly well straightened out on March 21st, when, with unwashed coke, 75 per cent. of fine Mayari nodules was put on the furnace for two days (see Chart I). Then the schedule of tests continued as follows:

Two days' run, unwashed coke, 75 per cent. fine Mayari nodules.

Five days' run, unwashed coke, 81.25 per cent. fine Mayari nodules.

Seventeen days' run, washed coke, 81.25 per cent. coarse Mayari nodules.

Six days' run, washed coke, 3 per cent. lime nodules.

Ten days' run, washed coke, high lime nodules.

Fourteen days' run, washed coke, screened nodules.

This brings us up to date and the tests are to be continued approximately as follows:

Ten days' test, washed coke, 81.25 per cent. sintered Mayari ore and flue dust.

Ten days' test, washed coke, 81.25 per cent. Mashek briquettes.

Ten days' test, washed coke, 81.25 per cent. partly dried raw ore.

Some of the points deserving especial mention as shown on Chart I. are: the sudden clearing up of the entire situation when the change was made from unwashed coke and fine nodules to washed coke and coarse nodules, showing increased product, improved yield of iron from ore, a drop in fuel ratio, a drop in the percentage of stone to ore, a reduction in flue dust produced, a remarkable drop of 3 to 4 pounds in blast pressure, an increase in the nickel content

of the pig iron, a drop in the sulphur content of the pig iron and the establishment of extremely regular, uniform furnace conditions with complete absence of any slipping or hanging. The high alumina, and high percentage of acids in the slag will be of interest.

During the entire run, the physical condition of the slag has been excellent. After flushes and casts, the runners contained practically no cinder, all having drained clean. The slag was invariably hot and exceptionally fluid. With silica plus alumina about 52 per cent., composed of approximately 29 per cent. alumina and 23 per cent. silica, good results were obtained. In fact it developed that variations in alumina from 27 per cent. to 33 per cent. and in silica from 20 per cent. to 25 per cent. had no apparent effect on the operation of the furnace. To me the temperature of the slag appeared far more important than its chemical composition. Our excellent coke gave an intensely hot hearth and no difficulty resulted in handling the slag and obtaining good iron. A slag volume of approximately 1,740 pounds per ton of iron was maintained in the various tests. A small amount of mill cinder—6 per cent. running about 29 per cent. SiO_2—seemed to help the slag conditions by increasing the SiO_2 about 2 per cent. in the slag.

The normal Mayari pig iron, analyzing about 1.00 per cent. Si., .03 S., 1.00 to 1.20 Ni., 2.00 to 2.40 Cr., presents very little grain in the fracture. This iron has as a rule a large crystalline structure somewhat similar to spiegel, although with higher silicon content and under conditions of slow cooling, it is not uncommon to find fractures exhibiting a full grain. However, the presence of chromium in pig iron seems to drive the carbon into the combined form, thus giving the spiegel effect. One great peculiarity of this iron is the high total carbon which in our recent tests averaged 4.65 per cent., and the high ratio of combined to graphitic carbon.

The results show very little if any advantage of lime nodules over straight Mayari nodules, but the chances are that the advantages of the former would be brought out to a more marked degree in a larger furnace, where the stock

	Lake Ore Dec., 1908	75 Per cent. Fine Nodules and Unwashed Coke	81.25 Per cent. Fine Nodules and Unwashed Coke	Coarse Nodules and Washed Coke	3 Per cent. Lime Nodules and Washed Coke	7 to 9 Per cent. Lime Nodules and Washed Coke	Screened Nodules and Washed Coke
Product, Tons	170.43	91.76	98.98	157.10	150.08	156.39	158.58
Actual Yield	.52	.51	.49	.59	.57	.58	.61
Theoretical Yield	.....	.59	.59	.605	.596	.581	.62
Fuel Ratio	1.15	1.43	1.49	1.15	1.18	1.15	1.13
Stone, per cent. of Ore	.....	.46	.46	.35	.33	.30	.38
Flue dust, per cent. of Ore	.....	.....	9	6	5.2	1.4	3.6
Blast Temperature, °F	735	1027	985	873	832	820	816
Blast Pressure, pounds	10	8.5	10	8	8	7⅔	8
Cubic feet Air per Min	21504	16212	18122	20482	20580	20580	20580
Chromium in pig iron, per cent.	.....	2.09	2.28	2.08	2.07	2.14	2.29
Silicon in pig iron	.....	1.48	1.40	1.06	1.01	1.07	1.24
Nickel in pig iron	.....	0.95	1.04	1.24	1.19	1.07	1.19
Sulphur in pig iron	.....	.043	.072	.041	.027	.039	.025
Sulphur in coke	.....	1.07	1.30	0.77	0.81	0.80	0.87
Ash in coke	.....	13.92	11.38	8.54	8.79	8.91	8.84
Sulphur in slag	.....	2.60	2.31	1.82	1.97	1.97	2.04
$SiO_2 + Al_2O_3$ in slag	.....	46.60	50.08	51.82	52.22	52.95	54.07
SiO_2 in slag	.....	25.70	24.11	22.58	24.19	23.81	24.30
Al_2O_3 in slag	.....	20.90	25.97	29.25	28.03	29.14	29.76
$CaO + MgO$ in slag	.....	49.76	.....	45.36	46.00	44.61	43.95
CaO in slag	.....	40.10	.....	37.44	37.51	36.68	35.94
MgO in slag	.....	9.66	.....	7.92	8.49	7.93	8.00
Ore on 10 Mesh	.....	.....	35.29	57.32	63.65	80.58	74.90
Ore Through 40 Mesh	.....	.....	15.50	7.10	5.30	2.24	6.47
Flue Dirt Through No. 10 on No. 20	.....	.....	8.18	18.13	23.45	16.73	6.22
Flue Dirt Through No. 40	.....	.....	60.75	28.83	19.77	22.09	36.61
Top Pressure, inches water	.....	.....	.....	1.2	1.25	1.14	1.17
Top Temperature, °F	.....	.....	.....	249	275	272	286
Moisture in Grains per cu. ft.	.....	2.7	3.5	2.5	4.0	3.6	4.7

NOTE—In slag analyses, the per cent. of CaO shown is slightly in error in so far as it includes the Ca as CaO which is combined with the S to form CaS.

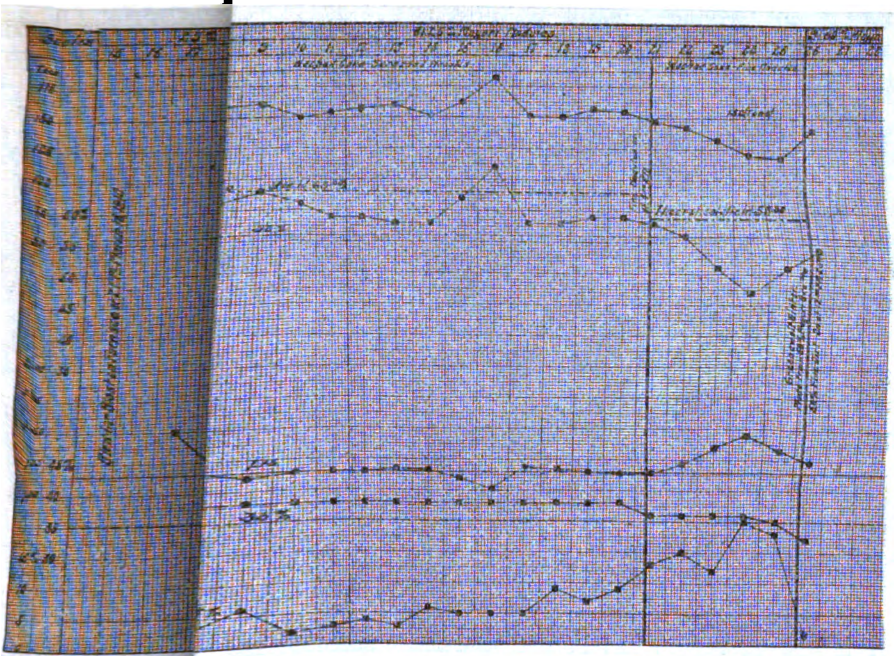
column is larger and where consequently more benefit would be derived from having the lime thoroughly mixed throughout the ore charge.

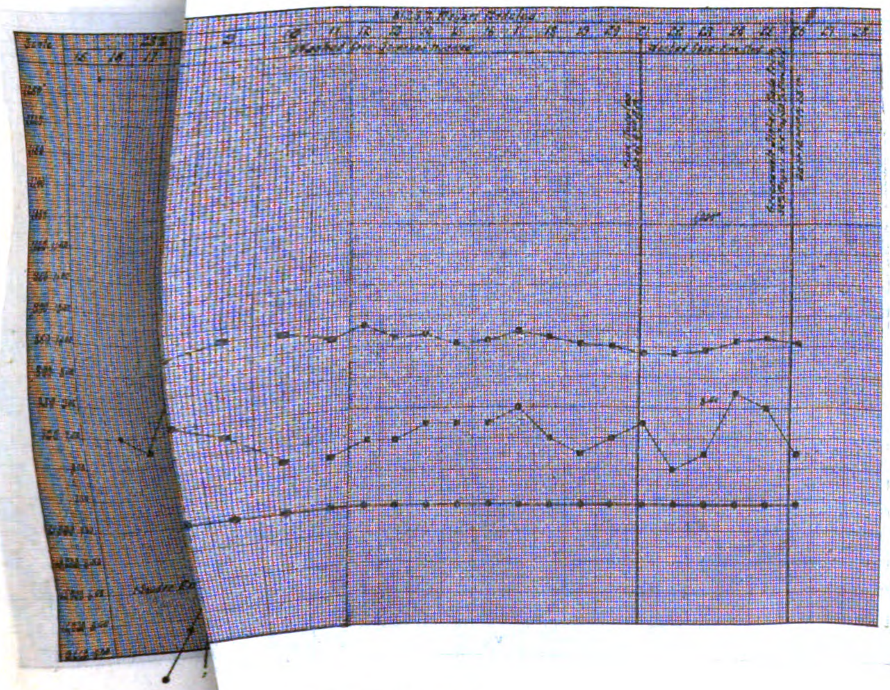
A summary of the average results from each test are tabulated on page 87, together with the data of the month of December, 1908, when No. 1 furnace made a record tonnage on a mixture of 75 per cent. Lake ore and 25 per cent. Daiquiri ore.

In spite of the favorable results obtained on this small furnace the great question now is, "How will a large furnace work on similar mixtures?" The results will no doubt prove better on a large furnace. This point will be demonstrated at Sparrow's Point by a conclusive run in the near future as soon as the coarse nodules arrive from Cuba. Already a short test run has been made on No. 1 furnace at Sparrow's Point, and the results were very encouraging. Following is the tabulated data covering the seven days during which more than 50 per cent. of coarse nodules were used in the mixture.

Date April, 1914	Per cent. Mayari in mixture	Tonnage	Fuel Ratio	Yield	Tons of Flue Dust	Average, 24 Hours				
						Pounds Blast Pressure	Pig Iron			
							Si.	S.	Cr.	Ni.
13	57.2	453	1.02	.58	92	15.75	1.05	.025	1.35	.73
14	56.4	404	1.12	.52	111	16.00	.97	.034	1.67	.96
15	61.2	434	1.01	.57	91	16.25	.90	.024	1.59	.97
16	62.4	410	1.06	.56	67	15.50	.91	.026	1.70	.96
17	62.4	423	1.07	.56	94	17.00	.93	.027	1.73	.95
18	61.0	448	1.01	.58	69	16.50	.71	.035	1.66	.89
19	62.0	397	1.08	.55	81	15.75	.88	.036	1.63	.89
Average	60.4	424	1.05	.56	86	16.50	.91	.029	1.62	.91

The nodules used for this short test were the same in size as those used on No. 1 Steelton furnace in a test made from April 1st to 17th, inclusive. They did not come up to the standard of 75 per cent. on the 10 mesh, falling as low as 57 per cent. on 10 mesh, consequently the flue dust produced was too high, averaging about 12 per cent. of the ore charged. With standard large nodules, it is expected to keep the flue dust down to 5 per cent. of the ore charged.





TEEL CO., STEELTON

Furnace Design.

With conditions relating to quality of coke and preparation of the ore in such an unsettled state and demanding the undivided attention of everyone concerned, there was but little opportunity to experiment with any radical departures in furnace lines. The furnaces used for experimental work were those called upon to turn out the regular grades of iron, so that with the limited facilities no changes could be made, even if desired, which would effect the furnace operations to a marked degree under any one of these varied conditions.

At Steelton, the furnaces, as at present lined, have given fairly good results on Mayari ores, at least, as good as could be expected in the face of other difficulties.

As to the question of bosh angles, No. 1 Furnace, Steelton, has 71°; No. 2 Furnace 76°; No. 3 Furnace 74°; and the latest lined No. 4 Furnace 77°. With coke and ore troubles fast improving, we are inclined to favor the larger hearth, steeper and shorter bosh for Mayari ore practice, yet it is doubtful if the 80° bosh furnace will work well on these more refractory ores. However, time and experience will, no doubt, demonstrate the best practice. Up to the present, it can be stated as a fact that practically no difference can be noted between the working of Mayari ore on a 74° bosh furnace as against that on a 76° bosh; therefore, I see no reason why even a steeper bosh should not work well.

MODERN AMERICAN BLAST FURNACE PRACTICE

EDGAR S. COOK

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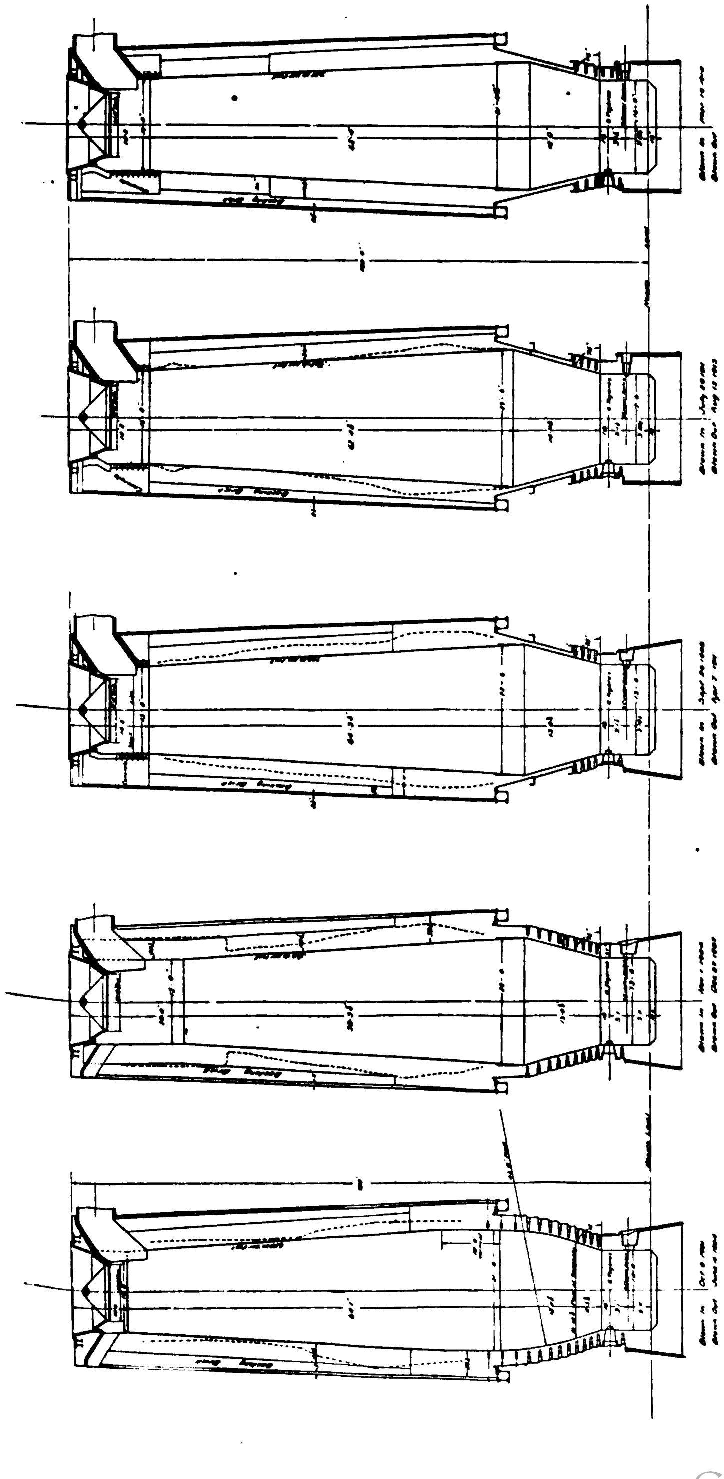
It is impractical, in the time allotted, to discuss many of the points brought out by Mr. Brassert in his interesting and comprehensive paper. I will therefore confine myself to the development of the lines of the modern blast furnace of the East, taking Warwick No. 2 as an illustration, and giving the records and brief information of the materials used and the furnace practice.

LINES AND RECORDS—WARWICK NO. 2.

The Chart on the opposite page shows the lines of No. 2 Furnace. The records of the work of this furnace are given in the Tables appended to this paper.

First Blast, 1901 to 1904. The lines of the first blast were obtained by practically making an enlarged photograph of the No. 1 furnace 70 feet high, which had done satisfactory work on merchant pig iron of various grades, using the usual materials commonly employed in the East. The records show that the first blast was extremely unsatisfactory. Passing through the period of organization on a new plant would account for some of the trouble, but the management felt that there were serious difficulties with the furnace itself.

Second Blast, 1904 to 1907. The lines of the second blast were copied from the Edgar Thomson standard at that time. It will be noticed that they are somewhat between the lines of "E" and "K" furnaces at Edgar Thomson, as shown in Mr. Brassert's paper. The decision to make this change was made after investigating the lines of most of the furnaces in this country which were doing good work. It was also decided—following this investigation—to eliminate all cooling plates above the top of the bosh. The work



on these lines was fairly satisfactory, as is shown by the records. The Gayley Dry Blast was applied at the end of this blast and the results published the following year.

Third Blast, 1908 to 1911. The hearth was increased in diameter and the bosh jacket was installed; also a revolving top was used and protection at the stockline. The only reason for blowing out this furnace was the failure of the hearth jacket. The wear lines were extremely uniform and the furnace inwall was in good condition when blown out. This was the most satisfactory blast.

Fourth Blast. In order to use the bosh and bosh jacket, this furnace was blown in with the same size hearth. In order to save time and brick and try an experiment, the bosh was made nearly 2 feet higher than in the previous blast. This furnace gave more trouble with sticking and high pressure from the start, and did not work satisfactorily for so long a period. The effect was as if the furnace was partly worn out when it was blown in.

Fifth Blast. The hearth was increased to 16 feet and the bosh angle made 76 degrees. The bosh is 12 feet high, nearly 3 feet lower than in the preceding blast. This lining has only been in operation for a few months and the furnace is doing excellent work.

A paper could be written about each one of these blasts concerning the troubles that were experienced and overcome, or that could not be overcome until the next blast.

The consistency of the work is particularly noticeable, on account of the various materials used.

On the other furnaces successful attempts were made to use larger hearths, somewhat steeper boshes, and with the bosh jacket so designed that no offset or step could form in the furnace. One furnace was built with a bosh only 9 feet high and gave good results.

Experiments were made on a smaller furnace as to the dimension from the center of the tuyeres to the beginning of the bosh slope. These experiments seemingly confirmed the German practice that there is an advantage in having this dimension large on foundry iron, and an advantage in

having it as near nothing as possible on very low silicon iron. For the average merchant furnace about 18 inches is apparently satisfactory.

Materials.

Ore. All kinds of iron-making material are available in the East—Lake Superior ores, magnetic ores of various kinds, Clinton ore and foreign ores from Spain, Sweden, Greece, Africa, Cuba, and mill products, cinder, scale and pyrites cinder. All of these materials were used in varying proportions at various times on the No. 2 furnace.

Titaniferous ores were not available. Mayari, and a Greek ore of similar analysis, were used up to 25 per cent. of the mixture.

The problem of making up a blast-furnace mixture, in order to make the most money, is an intricate one. Careful observation and experience showed that there were certain general rules which were carefully followed in making standard iron:

First: To maintain a base of at least one-third first-class hematite ore.

Second: Not to use iron-bearing materials of inferior quality or hard to reduce, except at a large differential in price, and then only in small proportions.

Third: Magnetic ores well prepared can be used up to 40 per cent. of the mixture without seriously affecting the fuel consumption and tonnage, although these ores increase the cares of the blast furnace manager and make it much more important to carefully watch the operations and maintain uniformity, particularly in the distribution of stock and air.

Fourth: Select ores to maintain the slag volume at the desired amount for the particular furnace on a particular grade of iron, and to also keep the slag uniform in that ratio of silica to alumina, which experience has shown to be the best.

Preparation of Magnetic Ores.

The successful use of magnetic ore depends largely upon its preparation.

First of all the ore should be so small as to be readily attacked by the gases. Crystaline ores can be crushed to pass a ¼-inch ring and only a trifling percentage will pass an 80-mesh sieve. This ore works well, making little flue dust. The difficulty encountered in its use is a tendency to run ahead like sand; this can be partly overcome by the filling. It should be kept out of the mixture while blowing in and increased in the mixture by small percentages.

Very fine magnetic ore should be mixed with flue dust and sintered, the resulting product being satisfactory. If used without sintering, the flue dust made is excessive and there is a decided tendency to build on the bosh of the furnace.

Both magnetic separation and cobbing are practiced to remove silica and phosphorus. Where sulphur occurs the ores are roasted, or sintered or nodulized and the sulphur eliminated or changed to a less objectionable form.

Some magnetic ores reduce quite readily in the furnace, and these do not require such careful preparation.

In recent years, much progress has been made in ore preparation with resulting benefit to the furnace practice. Not only are the ores more readily reduced on account of this preparation, but they are much more uniform and lower in silica.

Fuel. The fuels available are hard coal, West Virginia and Mountain cokes, Latrobe and Connellsville cokes. The best Connellsville and Latrobe cokes were found to be the cheapest fuel except under special market conditions. A great deal of attention was paid to obtaining a uniform coke of the best quality. Provisions were made in the laboratory to analyze each car of coke when necessary. Each car was carefully inspected to make sure that the coke was of proper physical quality to resist the destructive action of the gases in the furnace. Much attention was also paid to careful screening of the coke at the furnace, all coke under ¾-inch being screened out—this again being screened through a ½-inch revolving screen and separated from the breeze, the resulting size being used in a small regular percentage in the furnace when it could not be sold or utilized for any

other purpose. If the fuel mixture contains a large percentage of this small coke, sticking and other irregularities result in a short time.

The fuel records are based on railroad weights with no wastage deducted.

Flux. Pure calcite and dolomite stone are available, the latter being much the cheaper in cost per ton. All calcite or all dolomite was used at times according to the alumina content of the slag. There are some excellent records on dolomite stone with a slag carrying over 3 per cent. of sulphur for long periods. It was of course necessary to this condition that the slag should be bi-basic and the alumina low to prevent the formation of spinel. There is much less danger of lime scaffolds in the use of dolomite than in the use of calcite stone.

It was found desirable to keep the slags practically uniform in the relation of silica to alumina for various grades of iron, and the proportion of calcite to dolomite is therefore maintained practically constant, the rule being to use ¾ calcite and ¼ dolomite on basic iron, and on foundry iron ½ calcite and ½ dolomite.

The percentage of stone used varied at times from 18 to 45 per cent. of the ore mixture. The best work was done on 18 to 20 per cent. of stone on basic iron, and about 24 per cent. of stone on foundry iron.

It was found desirable to keep the stone uniform in size, and clean. The smaller sized stone is best for basic iron, as it seems to facilitate the use of a more acid slag.

PRACTICE.

The furnaces have always been carefully dried out before blowing in. The blow-in, such as used at Edgar Thomson, and described by Mr. Gayley in 1890, has always been the practice at Warwick, exceptional care being taken to see that small tuyeres are used in the blow-in, and that the tuyere velocity is kept as constant as possible as the wind is increased; also, that the wind and the heats are kept down until a heavy burden is at work so as to insure a low zone

of fusion. Care is taken in the first two weeks of the blast to coat the furnace with graphite in order to protect the brickwork.

As previously stated, fine magnetic ore is not used in the blowing-in mixture, but is added slowly.

Eastern practice varies so much with the special material conditions at many plants that little can be said of it in a general way.

In the past when acid slags were used on light burdens much trouble was experienced with high melted scaffolds. Later a change to very basic slags overcame the scaffold difficulty. The difficulty experienced with this practice was building on the bosh, and the fuels were high. Still later experience showed that with the use of better fuels and heavy burdens of well-prepared ore the heat can be kept in the hearth on a more acid slag. With this practice the fuels are lower and the building on the bosh is slower. However, the heat must be kept in the hearth, and if this cannot be done with burden it must be done with lime, whatever the consequences.

Sulphur is the usual limiting feature in acid practice.

For this reason all materials containing sulphur were avoided by us and an attempt made to run the furnace on a small slag volume and as acid as consistent with the making of good iron.

The troubles are high pressure and sticking, and the peeling off of the bosh with consequent overburdening, and closing of the tuyeres with iron.

Magnetic ores, particularly the finer ores, greatly increase the risks of furnace operation. The bosh jacket is preferred because as the bricks melt away the bosh plates can hold between them so much unreduced magnetic ore. A sudden cooling of the furnace due to water leaks or other causes, an error in distribution, dirty coke, and even suddenly cutting the heats too low, causes the carbon coating and accumulation of finely divided ore to come off the bosh. The consequent overburdening of an already heavily burdened furnace sometimes causes chilling.

For this reason great uniformity is required. The re-

volving top is practically essential. The relation of the bells to each other and the stockline, and the movement of the bells, is of great importance. The air distribution must be correct and the tuyere area very carefully fitted to the furnace and the practice. The length of tuyere is varied according to the quality of the iron and the condition of the furnace.

High uniform heats are essential to produce low fuel, as much of the magnetic ore must be reduced by the direct process of incandescent carbon.

The dry air plant is of great benefit, not only for the fuel saved but also because it eliminates the very expensive troubles which furnaces using magnetic ores experience during periods of high and irregular moisture. I feel that the dry air plant will be as well understood within a few years as hot blast stoves—that it is of great value under certain conditions, and a desirable luxury under other conditions. While many furnaces do not work well with high blast temperatures, our experience has been that with the dry-air blast we have been able to utilize the full power of our stoves, and this has been confirmed by Mr. Reese with the use of dry air at the furnaces in Cardiff, Wales.

The new lines and appliances have greatly decreased the difficulties. It is possible that steeper boshes, such as used at South Works, will be a further help. So far, however, we have been unable to build a furnace which will keep itself clean, and settle regularly, month in and month out. The records show that the work is good, but this is due to the prompt measures taken by a trained organization on the first sign of trouble.

Every irregularity is immediately given attention and an endeavor made to ascertain the cause. Small cleaning blanks are used or the furnace is run very acid for short periods. Large blanks or other excessive measures are used in case of emergency, as when the furnace starts to scour, with consequent cooling of the hearth and with the top of the furnace becoming hot.

Successful practice is closely allied to the construction. The ideal toward which we all strive is to so improve and

adjust our lines, construction, appliances and materials that the practice will be uniform and easy and consequently economical.

At first it was thought that the large furnace was only suited to the manufacture of basic iron. In the third blast foundry iron was made, 500 tons a day of high silicon on the lowest coke consumption known at the time.

After this low phosphorus iron was successfully made.

My remarks in regard to practice refer chiefly to basic iron. Foundry iron is made with less risk, although if low fuel consumption is expected the principles are the same. The margin of safety is greater on the foundry grades. A furnace that will do good work on foundry is often an absolute failure on basic iron, while the good basic furnace is usually an excellent maker of foundry grades.

Mr. Brassert's remarks in regard to organization cannot be too strongly emphasized. I feel that whatever success I have met with has been in a large part due to being able to interest the men, down to the keeper and cinder man, and, in the old days, the top filler. Often these men have given advance information, and have called attention to small details of operation which have proven of the greatest value in anticipating and correcting large troubles. Just as every detail of the operation should be studied, so should every man about the furnace plant be given attention, to the end that his eyes and brain may be utilized to secure smooth running.

Conclusion.

In summing up, the main points of interest are:

First: The Edgar Thomson furnace, which did the best work about 1900, using Lake Superior ores and making steel works iron, proved the most satisfactory furnace at that time for using the various ores of the East on merchant grades of iron.

Second: The development in the East has been along the lines of larger hearths and lower boshes, the same as the development in the West. Somewhat steeper boshes seem desirable.

Third: The large furnace, which at first was thought only suitable for making basic iron, has since been found to make all the grades of merchant iron—foundry, Bessemer, malleable, and low phosphorus—of a satisfactory quality, and with as low fuel consumption as the small furnace.

Fourth: Various difficult materials can be used up to a certain percentage, good work and long life be gotten out of a furnace, provided care is taken to see that the stock distribution and the air distribution are correct, and attention given to proper uniformity of operation.

It is hardly likely, as Mr. Brassert says, that there will be the development in the future that I have witnessed in the forty years that I have been actively engaged in the blast furnace practice. I feel, however, that new problems will be coming up from time to time, which will require the vigorous efforts of our best men to satisfactorily solve.

Moreover, it is sometimes hard to hold the advantage won. The older men pass on and, with the younger men lacking practical experience, errors creep in which are difficult to locate. Every mechanical genius cannot be expected to have the advantage of a blast furnace training.

The metallurgist must be always on guard to see that the mechanical engineer in improving construction does not interfere with the process.

There are no mysteries about a furnace, but there are many seeming mysteries which are usually a combination of a number of small errors, in construction, materials, fluxing, and management. These must be patiently sought out and eliminated one by one. Diagnosis is as difficult at times as the physician experiences in treating the human body.

YEARLY RECORD OF No. 2 FURNACE.

Year	Annual Tonnage	Daily Average	Pounds Fuel per Ton	Best Monthly Tonnage	Daily Average for the Month	Pounds Fuel per Ton	Annual Average Stone per Ton	Per Cent. of Burden of: Hard Hematite	Soft Hematite	Magnetite	Mill Products	Top Heats	Stove Heats	Yield of Ore
1902	115519	265	2810	10595	353	2815	1424	35	33	16	16	803	1043	53.0
1903	134019	381	2791	12620	407	2695	1300	30	30	20	20	673	1147	53.2
1904*	84735	420	2608	13147	424	2482	1159	34	28	25	13	668	1040	54.4
1905	163155	454	2359	14796	477	2296	1097	41	28	24	7	475	1036	53.1
1906	165548	474	2237	16509	550	2190	1069	42	32	18	8	378	984	53.8
1907*	156643	450	2378	15522	517	2320	1074	34	28	29	9	375	1066	56.0
1908*	48248	492	2094	16976	547	2035	962	46	20	23	11	395	1062	51.1
1909	189778	526	2067	17831	575	1962	887	42	18	35	5	386	1157	53.3
1910	179435	510	2089	17797	574	1947	848	40	30	27	3	377	1092	53.6
1911	122250	481	2149	15940	514	2106	885	40	20	30	10	379	1121	53.6
1912	183416	507	2050	16491	532	2000	931	52	15	28	5	373	1147	54.7
1913*	76775	468	2306	14975	499	2154	994	40	13	42	5	515	1075	53.7

* In blast 30 weeks in 1904.
* Furnace blown out, December 27, 1907.
* Furnace blown in, September 24, 1908. (Dry Air Plant installed.)
* Furnace blown out, August 13, 1913.

No. 2 FURNACE.
COMPARISON OF BASIC AND FOUNDRY PRACTICE.

Kind of Iron	Analysis			Mixture				Average Daily Tonnage	Fuel per Ton R.R. Weight	Limestone per Ton	Stove Heats	Top Heats	Yield of Ore
	Sil.	Phos.	Sul.	Soft Hematite	Hard Hematite	Magne-tite	Mill Product						
Basic..........	.49	.769	.040	19.6	47.6	27.8	5.0	575	1962	916	1157	386	53.8
Foundry......	1.80	.787	.034	23.5	38.0	31.4	7.1	483	2236	803	1180	528	53.3

RECORD OF BLASTS OF No. 2 FURNACE.

Period	Total Tonnage	Daily Average	Average Fuel per Ton	Average Stone per Ton	Ore Mixture				Yield of Ore
					Hard Hematite	Soft Hematite	Magnetite	Mill Product, etc.	
1st. Blast................	328251	360	2730	1294	33	30	21	16	53.5
2nd. Blast................	507631	456	2325	1080	39	29	23	9	54.3
3rd. Blast*...............	464434	512	2097	878	43	23	28	6	53.0
4th. Blast................	362963	491	2191	963	44	16	33	7	54.0

* Dry Air plant installed.

THE IMPORTANCE OF THE INVESTMENT FACTOR IN SALES POLICY

THOMAS J. BRAY

President, Republic Iron and Steel Company, Youngstown, Ohio.

I believe that upon consideration it will be agreed by men of experience in the rolling mill and steel industries that the "relative prices" of steel products are at the present time the lowest recorded in the history of the trade. By "relative prices" of steel products is meant, of course, their present selling prices as compared with wages and the prices of various commodities. In other words, the number of hours of labor, the number of bushels of wheat, or tons of coal, that a ton of steel will now buy is less than at any former period.

During the periods of extremely low prices of 1893–1894, and 1895–1898, which old time steel men always recall when discussing hard times and low profits, the selling price of a gross ton of steel billets would buy, roughly speaking, about 140 hours of unskilled labor, while now it will buy little more than 100 hours. The selling price of a net ton of merchant bars would then buy about 170 hours of unskilled labor, while now it will buy about 115 hours. Expressed in terms of mechanical labor, or mining labor, or in coal, or in terms of great commodities like wheat and corn, or in terms of taxes paid per ton of steel produced by steel companies, the same condition holds good, that the relative prices of steel products in this country are now lower than ever before.

This low selling price of steel products not only brings pressure on operating heads to reduce costs, but also necessitates, on account of the narrow margin of profit, extreme care in making sales.

It is obvious that under these conditions the fact that tonnage can be taken at the current market price is not a sufficient guide for taking or refusing it, but regard must first be had to the cost of producing the material. The sales manager, or head of the company, or whoever has the

last word in deciding day by day the prices to be put on products, or the length of time for which contracts shall be made, should have constantly before him complete cost data.

WHAT FACTORS CONSTITUTE COST.

For the use of the sales executive the total cost should be made up not only of the cost of material, labor, stores, scrap loss and other items necessary for operating comparison and control, but in addition there should also be included such items as the normal depreciation per ton of finished product, salaries, and general expense per ton of finished product, and other items which in an operator's cost sheet need not be allocated against the product. In short, the total costs of various products given to the sales executive, to be of use, should be so complete that if tonnage sufficient to give a full operation were sold at those costs the company would be able to pay all charges exclusive of interest on investment.

The importance of the subject of complete costs is my only excuse for the reiteration of matters which no doubt are well taken care of by the accountants of the various steel companies represented here.

In addition to the items just considered, and which I presume are covered in different ways by accountants in furnishing cost data against which sales are made, the sales manager, and other officers having to do with selling, should also, in considering sales at a narrow margin of profit, take into account the interest on investment per ton of each kind of product manufactured and sold. This was a matter of little importance when the total investment required was small and when the different steps in the process of manufacture from ore to finished steel were undertaken by separate companies and a profit was necessarily taken on each step. But with the integration of properties and processes there is a natural tendency to consider only one profit from ore to finished material; and it is obvious that unless this single profit is sufficient to give a fair return on the total investment the result will be, to say the least, disappointing.

To those of us who have had experience in the construc-

tion of steel plants, rolling mills, and so on, during the past twenty years, one of the most impressive features has been the progressive increase from year to year in the cost of construction, which of course has meant a corresponding increase in the amount of money invested. Not only has the influence of higher wages and generally higher equipment costs made itself felt in higher construction costs, so that the plant built in the early nineties, or even ten years ago, could not be duplicated today for its original cost, but changes in processes, in raw materials, and a variety of other causes have had their effect in increasing the investment factor.

Construction Costs Then and Now.

The typical American steel plant of the decade ending in 1900 may be said to have been an acid Bessemer works, which on account of the then low price for fuel, could be operated economically with a very cheaply built power plant. This fact, together with the simplicity of the process itself. meant a low investment per ton of product produced. Due largely to the decreasing supply of low phosphorus ore, the typical American steel plant is now a basic open hearth works. The investment per ton of ingots necessary to carry on the process from pig iron to ingots in a converter plant is about one-fifth of the investment per ton for the corresponding step in an open hearth steel works, so that the effect of the change of process on the investment factor is easily seen. It is true that it is sometimes maintained that, inasmuch as the ordinary open hearth plant uses only say 60 per cent. to 70 per cent. of a ton of pig iron per ton of ingots, this lessened need for blast furnace capacity (pig iron being replaced by purchased scrap) might be considered as an offset to the higher investment in the open hearth plant. But in my judgment this factor cannot be considered an offset, as the supply and price of scrap are at least as uncertain at the present time as was the ability to buy for extended delivery cheap Bessemer pig iron in the earlier years. The fact that in some cases the Duplex Process with its high pig iron consumption has been used, partly because of the uncertain scrap supply and its uncertain price, bears out this thought.

Factors Increasing Costs of Construction.

Furthermore, leaner ore has its effect on blast furnace tonnage, so that in general, the production of pig iron per cubic foot of blast furnace capacity is being lessened from this cause year by year, although this tendency may not be felt by those having ample supplies of rich ore.

With the increasing cost of fuel have come large increases in investment in the power plants of blast furnaces and steel works. Higher priced fuel has justified fuel economy, and the use of stokers, super-heaters, compound engines, condensers, low pressure turbines, gas engines, and electric mill drives. These improvements while necessary to combat an increasing fuel cost do not of themselves necessarily increase tonnage, and have a tendency to increase the investment factor per ton of steel produced.

Among other causes which might be mentioned tending to increase this factor has been the "Safety First" movement, improved sanitation, better housing conditions, etc., all commendable and necessary, but all tending to a higher investment per ton of steel produced.

It is also a fact that the large investments in plants have brought with them and made advisable the investment of money in large reserves of ore and coal, and the equipment that goes with them. Common prudence has dictated that the large investment in modern plants should be backed up by a reserve of raw materials. This was not so necessary in the early days of the steel business, when the plant investment was small and the limits of bodies of desirable ore and coking coal, within reasonable transportation distances from steel producing centers, were not so well defined. Leaner ore has also meant investment in concentrating and washing plants, and as the proportion of ore mined from shafts increases as against that from open pits, larger investments may become necessary because of this fact.

Some Factors Helping to Reduce Construction Costs.

It is true, that the ingenuity and organizing ability of the steel maker, engineer and operator have been able to

counteract to some extent this increase in investment. Through the growth of individual steel companies, or the combination of small companies to form large ones, a degree of specialization of operations on finished product in various lines is now possible which was impossible under former conditions. With larger tonnages under the control of single organizations, rollings come in sufficient quantity of one size to warrant, to a greater degree than formerly, the installation of special large tonnage mills. This fact together with the elimination of the former arbitrary limitation of output by labor on certain products have been the special causes which have served to offset in a degree the growth of the investment factor.

I believe I have given enough reasons for the consideration of the investment factor by the sales executive, especially in low priced times, like the present. An easy way to handle this question for sales purposes is to work out an investment factor per ton of capacity per year for each product sold, taking into account not only the money invested per ton produced, in real estate, plants, etc., but also the approximate amount of working capital required per ton produced per year for each product sold.

Some Construction Cost Items Considered.

Without attempting to give close figures, which of course, differ widely with different conditions, but simply for illustrative purposes, let us consider a modern steel company of moderate size, producing, say, 400,000 net tons of open hearth steel merchant bars and plates per year. Such a concern, if built up under present construction conditions, will probably, if provided with coking coal reserves for twenty-five years, have an investment in houses, coal shafts, mining equipment, coal reserves, and by-product coke ovens, of from \$7.00 to \$10.00 per net ton of capacity of finished steel per year. In blast furnaces its investment will be from \$8.00 to \$10.00 per ton per year of finished steel. Its open hearth plant, blooming mill, and billet mill will entail an investment of from \$13.00 to \$15.00 per ton per year of finished steel. Its bar mills and plate mills will require an

investment of $7.00 to $8.00 per ton per year of finished steel; while the working capital required will probably be from $10.00 to $12.00 per ton per year of finished product. I hesitate even to guess at the investment in real estate required per ton of finished steel, but it can easily run $1.00 to $2.00 per ton per year of finished product produced; while the consideration of the value of ore in the ground—depending as it does upon so many factors, like quality, cost of mining, and transportation—would take a separate paper and for brevity is omitted. If part of the steel produced by the open hearth plant, instead of going into bars or plates, goes into more highly finished products—like pipe, wire, sheets, tinplate, shafting, spikes, or into fabricated structural work—the investment factor per ton per year for those products will be increased commensurate with the character of the product; or if part of the product is sold in the shape of billets, or sheet bar, the factor will be decreased for those products. In any case, the accountant can work out the investment factor per ton per year for each product along the lines indicated, taking into account the working capital required as well as the fixed investment.

While the figures given above are intended merely to be illustrative, they are based on experience, and in the example cited, would show that without ore or transportation interests an investment factor of from $46.00 to $57.00 per ton per year is indicated. This would mean, taking the average of the two figures, ($51.50), that to make 6 per cent. on the actual money invested a profit above full and complete costs is needed of somewhat more than $3.00 per ton on each ton of steel sold. Of course, if the interest on investment on money tied up in ore operations and properties per ton of steel produced were added this amount would be still higher.

Conclusion.

I have tried to bring out briefly the importance of the investment factor in sales policy; but I realize that the stress of competition, the attempt to stimulate business by low prices, and the effort to keep operating may at times prevent its consideration. This may be necessary in choosing the

lesser of the two evils—that is, of closing down the works, or completely neglecting profits. But I believe that, even in hard times, the constant consideration of this factor together with true costs will at least tend to make the comparative prices of different steel products more in keeping with their relative cost and with the investment necessary to produce the products.

The statement made at the beginning of this paper concerning the relative prices of steel and rates of wages shows that the public has, on the whole, been well served by the steel industry, and that with higher wages, higher taxes, etc., steel prices have not been increased in proportion.

There is also a duty to stockholders, and if constant consideration of the investment factor may not prevent ruinous prices for spot business, it is hoped that its consideration in sales policy will tend to minimize the extension of these prices over long periods.

THE IMPORTANCE OF THE INVESTMENT FACTOR IN SALES POLICY

C. SNELLING ROBINSON

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Mr. Bray's paper is a real message, and in it he has advanced ideas of vital importance to those interested in the manufacture and marketing of iron and steel products.

The prominent points brought out are:

That the present prices of steel products as measured by purchasing power are less than ever before;

That the plant cost per ton of steel produced is greater than ever before;

That the "Investment Factor" is often not given the consideration that it deserves as an element of cost;

That there should be a close relationship between sales policy and costs.

INCREASED RETURN TO LABOR.

The low selling prices of steel products have been effectively measured by their values in labor, wheat and other commodities, and a careful examination of the statements made presents to us the fact that the proportion of costs due to wages has increased nearly 50 per cent. since the low periods mentioned by Mr. Bray. As labor constitutes the largest single item in the cost of any steel product—authorities placing it in some instances as high as 90 per cent. of the total—it is evident that the values of steel products have been largely effected by the liberal reward labor has received.

RETURNS TO CAPITAL.

Admitting that plant cost per ton of steel produced is more now than ever before, due largely to the cost of improved and labor-saving machinery and to changes in methods and processes, and recognizing that labor itself has

been generously requited—how has capital fared? The average return covering the last fifteen years has been satisfactory—and represents a reasonable profit. The earnings, however, for the last six months or more have not only been inadequate, but reflect a condition under which only the most modern plants, carefully financed and economically managed, could continue to exist, provided due regard were given to proper maintenance and depreciation charges.

The steel companies, as a rule, are managed by men above the average in sagacity and business ability, but it would appear that through the integration of properties the responsible heads of large companies may have become less mindful of profits on the separate progressive steps of manufacture than they were formerly when a profit on pig iron, on ingots, on blooms and on sheet bars was essential. The apparent tendency is to consider only a final profit on the article sold, and as a result in times of financial stress or business strife the "Investment Factor" may become obscured or entirely lost sight of. As an example, when this factor is properly considered the so-termed independent sheet mills are at present buying bars from producers at less than cost.

Sales Policy.

Mr. Bray makes a strong plea for a close relationship between sales policy and costs, and gives cogent reasons why the "Investment Factor" should always receive careful consideration in making sales.

If some steel companies do relate their sales to costs, it is obvious from certain recent prices, that all do not, or that at times many purposely neglect them. In other words, the policy of meeting the market is now much in evidence; a policy liable to be based on ruthless competition, and as ordinarily applied utterly disregardful of knowledge or consideration of costs. By it prices are simply met, many of them being phantasmal or those quoted by irresponsible or financially weak bidders; such a policy tends to inefficient effort on the part of sales managers and to trade demoralization.

On the other hand, a policy which gives due considera-

tion to costs tends to greater efficiency and to better trade conditions. Even those who hold that cost has little or no bearing on selling price must acknowledge that the psychological effect of knowing that a certain price must be obtained to avoid loss is in itself a marked stimulus to effort for greater returns.

Information for Sales Managers.

Recently the necessity for extras and their maintenance was ably discussed before this Institute. To assist in holding prices at a profitable level the sales manager, or whoever is responsible for sales policy, must be conversant with costs. To that end monthly statements should be available showing in their relation to each other complete costs, sales expense, the "Investment Factor" (made up of, say, 6 per cent. on working capital and investment in plant and 5 per cent. for depreciation) as well as the net prices obtained. The costs should be so sub-divided that they are adequate for intelligent guidance. The "Investment Factor" should vary in proportion to the normal tonnage on different sizes and kinds of product made in the same mill in a given time. The prices received for individual articles should be less cash discount and claim allowance, as the granting of unjust claims can be made a virtual price reduction. This information—no matter how imperfect may be the sales lists, standard discounts or differentials—would make clear what is the most desirable and profitable business, and should bring those who have been in the habit of selling by meeting the market regardless of whether the articles sold are more or less highly finished, to a realizing sense that the "Investment Factor" should not be lost sight of. It would show that in order to cover this item where billets and sheet bars might call for $2.00 to $3.00 per ton sheets and wire products would probably call for from $4.00 to $5.00 per ton.

Extent of Operations.

Without doubt one of the most difficult problems confronting the heads of our large companies is the question

of how to operate their plants during periods of depression such as we are now passing through.

At times of inactive buying, with diminished production and low prices, a way of decreasing cost, at least to the extent of the increased efficiency of labor, is open to all; and if at such times each would be content with a proper percentage of the business offered and seek to make other cost reductions, it is believed that in the long run a larger return would be made on the investment.

Taking orders at such times in the endeavor to run full and thereby lower cost, or with the hope of stimulating the market, or perhaps of causing weaker concerns to retire from the field, ofttimes proves to be inexpedient. Specifications do not always come out, and the older and less extensively equipped plants can well give smaller consideration to the question of the "Investment Factor" than many of the more modern ones. Their owners also at times disregard everything but manufacturing costs, cutting their labor (which is a much larger percentage of their cost) to the lowest point and continue to run. Therefore large companies, or the new ones which without proper regard to costs try to secure enough when orders are scarce to enable them to operate in full, must eventually find that they have injured themselves, and possibly more than their competitors.

Let us, then, be satisfied with our just proportion when trade requirements are not normal, and not neglect overhead charges beyond what a corresponding curtailment of output would temporarily warrant.

CONCLUSION.

Finally, in considering the problems which enter into the iron and steel business, we should have in mind that success is pre-eminently the goal all are striving for, and that in the last analysis the man responsible for it will be held strictly accountable by his stockholders.

If success is to be attained it must be through the most careful attention to operating costs, backed up by a sane selling policy—a policy that considers all points of cost and that appreciates the fact that the invasion of another's

legitimate territory must bring retaliation and harmful results.

There is such a policy; it can be pursued; and it is enlightened, being based as it is on an intimate knowledge of costs and market conditions and on co-operation and justice. By no other policy can prices be obtained that will subserve the true interest of labor, of capital and of the public.

THE INFLUENCE OF THE INVESTMENT FACTOR ON SELLING POLICY

HARRY D. WESTFALL

Vice-President and General Manager of Sales, La Belle Iron Works, Steubenville, Ohio.

When invited to discuss this subject I thought of many things that have happened during the last few years, all having an influence on costs; but Mr. Bray has covered the ground so thoroughly that he has not only captured my first inspiration but has gone so much deeper into the subject that I consider myself fortunate to be able to second the motion.

A very complete statement has been submitted of new and proper factors in cost distribution; but the subject, if we are generous in our interpretation, has many angles, and the time seems opportune to make at least delicate reference to certain other features of its every-day application. It has doubtless been the experience of many, if not all of us, that we have regarded with some alarm the steady and probably permanent increases in producing costs; and I have found at times that a sober, second consideration of what we do, has frequently helped in making up our minds as to what we should do.

We all maintain elaborate accounting departments and regard them perhaps as the most necessary unit in our organizations. But, is it not a fact that we too often view such important data in the light of comparisons with the previous month, or with other years, rather than to be impressed with the vital influence it should exercise in the preparation of our price schedules? I venture to assert that we are not getting our full money's worth out of our actual costs, and I also contend that if a cost system is to mean anything it must be permitted to exert a controlling influence on prices. I believe this for the reason that the difference between a sales policy

based on cost and a sales policy based on something else is the difference between a sure profit and a hoped-for profit. There is no doubt that the man who is given the power to say the final Yes or No about selling should have (and always may have) a good working knowledge of the results of modern cost accounting; but it is my impression that we do not seriously consider costs except in case of last resort, or when competition becomes so severe that we know it would be wrong to go further. Then, it is, that we look around for some argument to fortify our courage in saying "No." In defense of this statement I submit that certain articles are today selling for less money than back in the nineties, and Mr. Bray has clearly proven that the cost of manufacture is several dollars per ton higher.

Do not gain the impression that I think costs are ignored, for they are not. All of us have spent many interesting and beneficial hours analyzing cost sheets; but when it comes to making prices, the easiest way is to make them upon what we think trade conditions are. When the demand is normal, or above, we endeavor to secure all the commodity will bring, and when conditions are reversed we force ourselves to be content with what we think competition requires. Neither is exactly right, for in each case values become to a certain extent speculative, either too high to stimulate continued consumption, or too low to encourage confidence. Both also suggest interference, for the former prevents a healthy growth of the industry and the latter is unfair to the capital invested.

If we keep moving in the same direction as in the past, it is only a matter of time when unusual profits during any period will be questioned; and if we are not permitted to anticipate a reversal in demand by creating reserves that will carry us through the famine, our better judgment will surely force the adoption of total cost *plus*, for a selling price.

Now, then, what are we going to do about it? In our personal relations we adjust our living expenses so as to harmonize with our incomes, and I ask if we do not owe it to ourselves and to our employers to adopt similar methods in conducting the business affairs entrusted to our care?

Mr. Bray concludes that under normal operating conditions an average profit of $3.00 per ton on the raw steel produced is necessary in order to guarantee 6 per cent. on the investment, with the proviso, however, that this does not include interest on the investment that has been made by most of us for the next generation. I would add that neither does it provide for irregularity of output due to the business public making up its mind periodically to cease buying.

It is not my mission to attempt to define a sales policy that would be proof against losses, for competition will always play an important part, and those of us who are anxious for success will meet the situation. But there is always a right way, and I maintain that what is fair and reasonable is above criticism. So why not base your selling prices, in good times or bad, upon mill costs, plus overhead, and then plus a reasonable rate of profit? If this plan were generally followed, I predict that actual selling prices would not, in any locality, vary more than they do now, and it would serve the purpose of removing certain kinds of demoralization which is about the most difficult thing we have to contend with.

To carry this phase a step further, we have frequently thought in connection with our own business that it would be feasible to establish a dead line, well within the limits of safety, at a point, say, that would relieve us from the charge of dissipating our reserves of ore and coal that cannot be replaced. We have reasoned that it has never been proven unfair or unjust to preserve a return on the investment for next year if it cannot be had during this year; but with a let-up in demand comes a terrible desire to run, and this coupled with competition as we find it, plays havoc with all such good resolutions.

There are other ways, perhaps more scientific, of arriving at a better method of making prices based on costs, and I can only suggest that we, as individuals, solve the problem in the manner best suited to our own industries. Sometimes I think that it would be well if the members of this Institute should indulge in dreams similar to those referred to infor-

mally at the Chicago meeting, and imagine their stockholders always in a happy frame of mind, secure in the belief that even if there was not enough business to go around, their holdings were not in temporary jeopardy. And then, after we wake up, handle our business in such a way that, regardless of output, we would insist upon a decent return upon the volume transacted.

My remarks may seem visionary to an extent and at variance with the fixed law of supply and demand, but each new year brings new ways and methods. We are no longer jealous of the prosperity of our competitors. There is more of a spirit of co-operation between buyer and seller than formerly existed. So why is it not fair to presume that, as we progress, a proper return on the capital invested in legitimate enterprise can be practically assured? This ean be accomplished only when we arrive at the sane method of studying our costs first and making our prices afterwards.

THE PRACTICAL IMPORTANCE OF HEAT TREATMENTS IN THE STEEL WIRE INDUSTRY

John F. Tinsley

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The use, in the wire industry, of heat treatments in the broad definition of the term, is very old. In fact, the development of the wire business has been due primarily to an early appreciation and application of such fundamental heat treatment processes as annealing, hardening and tempering.

In the manufacture of wire, heat treatments take not merely an important position but an indispensable one, with a scope of application far broader perhaps than in any other branch of the steel industry. This is, of course, to be expected, not only because of the multiplicity of uses under the most exacting requirements of service to which the enormous tonnage of wire is put, and not only because of the extremely small individual parts manufactured from wire, but also because of the extraordinary amount of work required in reducing steel from the ingot, in which it is originally cast, to the comparatively small section of the finished wire. A better appreciation of the latter fact may be had when it is realized that a 2-ton ingot, when rolled and drawn into the average size telegraph wire, becomes elongated upwards of 20,000 times its original length.

The principal heat treatments used in the manufacture of wire, are: (1) annealing; (2) patenting; and (3) hardening and tempering. The object of this paper is to present as comprehensively as possible, consistent with the brevity that is necessary in the treatment of a very broad subject, a discussion of the practical application of these basic heat treatment processes, which affect by far the largest tonnages in the manufacture of steel wire.

THE FUNCTIONS OF ANNEALING.

In discussing heat treatments of steel wire, that of annealing naturally comes first, because it is the most common of all heat treatments applied to wire, being practically the only heat treatment to which the enormous tonnage of soft or low carbon steel wires is subjected, although the annealing of higher carbon wires for specific purposes, as will be outlined later in this discussion, is an important and growing field.

Annealing serves to accomplish three important functions: (1) To remove the effects of hardening due to cold work in wire drawing or cold rolling, thus making the steel ductile and soft. Annealing for this purpose covers principally the low carbon wires, i.e., with carbon .25 per cent. and under. (2) To refine grain—applied principally to the higher carbon rods and wires, i.e., with carbon .30 per cent. and over. (3) To obtain definite structure in the finished material—applied principally to the higher carbon wires, i.e., with carbon .30 per cent. and over.

Removing the Effects of Cold Work.

The first class of annealing to be described covers low carbon steel which, under the microscope, shows a structure consisting chiefly of a mass of grains of iron interspersed with dark patches. These dark patches contain practically all of the carbon of the steel in the form of iron carbide. The other ingredients of ordinary steels, such as manganese, sulphur, silicon and phosphorus, are not satisfactorily detected by the microscope; and, as they do not affect the structure of the steel appreciably, their effect may be neglected in this study of heat treatments, which is chiefly concerned with structure.

The structure presented by annealed steel depends principally upon the carbon content, and, as will be shown later when the heat treatment of the higher carbon steel wires is discussed, there is a marked difference in structure between the various carbons.

Fig. 1 shows a photomicrograph of a small section of a

specimen of an .08 per cent. carbon steel with a magnification of 100. The lighter grains occupying the greater portion of the area are iron, while the black areas contain the iron carbide (Fe_3C). As a matter of fact, these dark areas are made up of plates of extreme thinness of iron carbide alternating with similar thin plates of iron, and forming together a constituent characteristic of annealed steel, known to metallographists as "pearlite." This structure is apparent only with very high magnification and is shown more clearly in Fig. 7.

The Effect of Wire Drawing.

When a steel wire rod of the structure shown in Fig. 1 is subjected to the wire drawing process, a marked change in the grain structure takes place. With each successive draft, the grains stretch out in the direction of drafting until a point is reached when the grains have been elongated to the limit of their ductility. If subjected to further strain by further drafting they will part and the wire will break. Before this brittle condition is reached, therefore, it is necessary to heat treat the wire by subjecting it to what is known in the wire business as a "process annealing."

The effect of wire drawing in elongating the structural grain of the steel may be seen by comparing Figs. 1, 2 and 3. Fig. 1 shows the structure of the rod before drawing; Fig. 2 shows the structure after a 15 per cent. reduction from the rod; and Fig. 3, the structure after a 60 per cent. reduction from the rod. All of these photographs represent sections taken from a plane parallel to the axis of the rod or wire, not cross sections. The reason for the marked difference in grain shown in Figs. 1 and 3 may be grasped more clearly when it is appreciated that Fig. 3 represents a wire reduced in the wire drawing process to such a degree that it has become elongated 2 1/3 times the original length of the rod.

The Effect of Process Annealing.

Process or "Works" annealing consists in heating the wire to a certain temperature, maintaining such temperature until the entire mass of steel is thoroughly heated

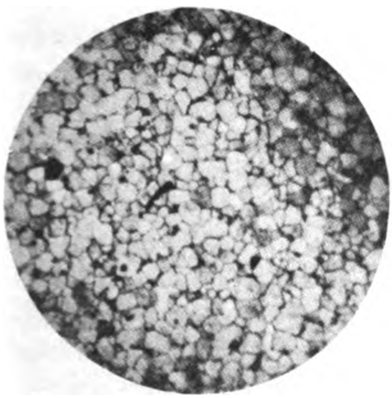


FIG. 1.—Steel, .08 carbon, annealed. × 100.

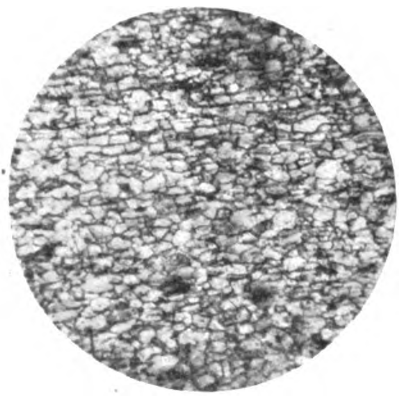


FIG. 2.—Steel wire, .08 carbon, given one draft, 15 per cent. reduction from rod. × 100.

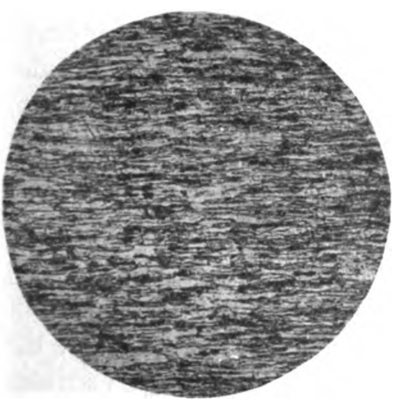


FIG. 3.—Steel wire, .08 carbon, given several drafts, 60 per cent. reduction from rod. × 100.

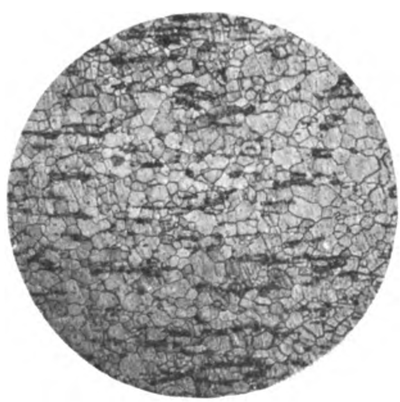


FIG. 4.—Steel wire, .08 carbon, hard drawn and then annealed below critical temperature. × 100.

through, and finally cooling down. Practically all prominent authorities on the metallurgy of steel state that the temperature of annealing must be above the critical temperature, which briefly defined is that range of temperature above which the iron and iron carbide are mutually in solid solution. Few of our authorities, however, seem to recognize the fact that in the most common of all annealing of steel wire—that to remove the effects of cold work such as drawing—it is not necessary to reach the critical temperature, which is 1300° F., or higher, depending on the carbon content. A temperature of 1100° F. is entirely sufficient to relieve the strained condition of the grain shown in Fig. 3.

Fig. 4 shows the same wire that is depicted in Fig. 3 after annealing at a temperature below the critical range.

In the annealing process the strained and elongated grains shown in Fig. 3, break up and rearrange themselves to form a new grain structure as shown in the photograph. The annealed steel of the structure shown is now in excellent condition to withstand further cold work in reducing it to finer sizes; or, if already at finished size, is in good condition to meet the demands of annealed wire service.

The effect of reduction of section incident to wire drawing on the tensile strength and ductility of steel wire, and the marked change brought about in these characteristics by annealing, as just outlined, is shown in Table A. This table is based on drafting and annealing practice in reducing a low carbon steel rod—in this case .10 per cent. carbon—to a fine size of wire. It will be noted that between 80 per cent. and 90 per cent. reduction from the rod or annealed wire can be taken before annealing is necessary.

In cold drawing from a soft rod or annealed wire, the heavier drafts can be taken when the material is in a relatively soft condition. The smaller the wire section the smaller the amount of reduction that can be taken, due to the reduced ductility of the wire and to its consequently lessened ability to withstand the heavy strains put upon the wire in pulling it down through the die. It should be understood of course that wire drawing practice is based also on other important conditions, such as speed of drawing and die lubricant, as

well as fundamental conditions relative to the size and uniformity of the rod, thoroughness of acid cleaning to remove the hard scale of ordinary hot rolled rods, and thoroughness of baking to remove the acid brittleness consequent to the cleaning process.

It is found in practice that in cold drawing from a soft rod or annealed wire, the increase in tensile strength is a direct function of the amount of cold work, almost independent of other conditions. Annealing practically brings the rod or wire, regardless of size, back to its original condition with regard to tensile strength and ductility. The increase of tensile strength and the effect of annealing as shown in the table, are illustrated more clearly in Chart I, from which it will be seen, that starting with a rod, there is

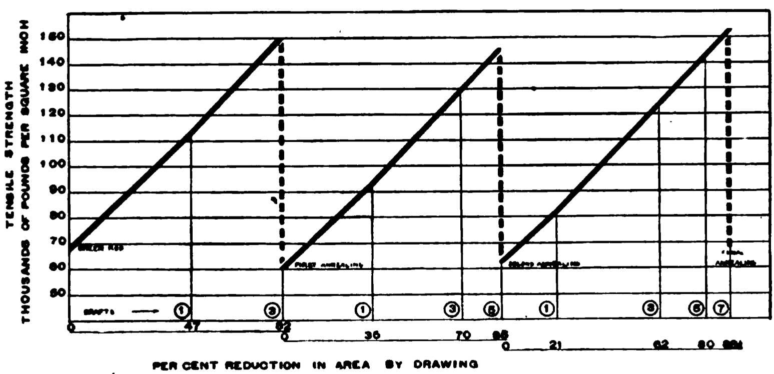


Chart I.—Showing increase of tensile strength due to drawing, and the effect of annealing, low-carbon (0.10 per cent.) steel.

a steady increase in tensile strength up to the annealing point, that the first process annealing reduces the strength of the wire practically to the original strength of the rod, and that the same relation holds in regard to any further drafting and annealing beyond this point. Of course, the results obtained on any two wires are not exactly alike but, if tests of a large number of samples were plotted, the line shown on the chart would represent good average practice. It will be noted that the final annealing does not bring the tensile strength as low as previous annealing. This is due simply to the fact that in annealing the fine sizes it is usual,

Condition of Material	Green Rod #5 Ga. .207"	First Draft	Third Draft	Process Annealed	First Draft	Third Draft	Fifth Draft	Process Annealed	First Draft	Third Draft	Fifth Draft	Seventh Draft	Annealed
Per cent reduction by drawing	0	47	82	0	35	70	85	0	21	62	80½	88½	0
Tensile strength pounds per sq. in.	68 000	113 000	150 000	60 000	93 000	130 000	145 000	62 500	82 000	124 000	143 000	151 500	68 000
Per cent elongation in ten inches	25	2½	1½	30	3	2	1½	28	3½	2	1½	1	25

Table A.—Showing the effect of cold drawing and annealing on the physical properties of low carbon (0.10 per cent.) steel.

Note.—Dead soft annealing gave a tensile strength of 50,000 and an elongation of 32 per cent. both at the first and the second annealing.

Condition of Material	Green Rod #5 Ga. .207"	First Draft	Second Draft	Patented	First Draft	Third Draft	Fourth Draft	Patented	First Draft	Third Draft	Fourth Draft	Patented	First Draft	Third Draft
Per cent reduction by drawing	0	28½	51	0	30	50½	65	0	30	66	76	0	30	66
Tensile strength pounds per sq. in.	95000	122 000	146 000	115000	143 000	163000	176 000	128 000	156 000	190 000	208 000	156 000	184000	218000
Per cent elongation in ten inches	10	2.9	2.8	8.2	2.8	2.7	2.6	7.8	2.0	1.9	1.8	6.0	2.0	1.9

Table B.—Showing the effect of cold drawing and patenting on the physical properties of higher carbon (0.50 per cent.) steel.

Note.—At the first patenting stage, process annealing gave a tensile strength of 70,000 and 18 per cent. elongation.

in order to avoid the mechanical sticking of the wire in coils, to anneal at slightly lower temperatures than in ordinary process annealing.

The Effect of Dead Soft Annealing.

In describing annealing to remove the effect of cold work incident to drawing, emphasis has been laid upon the fact that, to secure structure well suited to withstand further drawing, or in the case of finished wire to meet ordinary requirements for annealed wire, it is not necessary to employ temperatures above the critical range. However, the structure obtained in this manner is not quite the same as that obtained when the steel is annealed at temperatures above the critical range (1,300° F.) nor are the physical properties of the same wire subjected to these two different annealings exactly the same. In the latter form of annealing we would obtain what is termed in the wire mill a "dead soft" annealing, which is required for certain classes of finished wire subjected to very severe heading or upsetting operations.

The effect of "dead soft" annealing upon the physical properties of wire is shown below the process annealing column in Table A. The reason for this difference is that in heating above the critical temperature range the pre-existing structure is entirely obliterated, due to the iron and iron carbide going into solid solution and in cooling down forming a new structure. On the other hand, in annealing below the critical temperature the pre-existing structure is simply broken up and re-arranged but not entirely obliterated, and the deformation introduced by the cold work is thus not entirely removed.

In the annealing of low carbon steel wire, the rate of cooling from the annealing temperature is of little consequence as affecting structure, a fact which is much appreciated in the wire industry.

Refining the Grain by Annealing.

The second important function of annealing is that of refining grain, and its practical application in the wire mill

covers principally the medium and higher carbon steels. The structure of wire rods with regard to size of grain is dependent upon the temperature at which the rods are finished in the hot rolling mill and upon the rate of cooling through the critical temperature of the steel. In steel of low carbon this is not of as much importance as in the higher carbon steels, for the reason that the ordinary finishing temperature variations of good rolling mill practice have less effect on grain structure of soft rods, and therefore less effect on their physical properties. In higher carbon steels a fine grain is important, for it is this structure that makes for such steels their field of usefulness, where high strength, high elastic limit and great toughness are required.

Cause of Coarse Grained Structure.

Theoretically, the ideal structure would be obtained if the entire rod could be finished at about the critical temperature. But this is, of course, impracticable, for the reason that it is impossible to regulate the finishing temperatures so closely, and for the additional reason that there is, necessarily, particularly in rolling very long lengths of very small sections, a marked difference between the finishing temperatures of the first and last end of a rod. The higher the finishing temperatures above the critical range the coarser the grain, and the coarser the grain the more does the steel lack the qualities that give it value. In order to destroy the coarse or uneven structure that may be created as just described, it is necessary to anneal the steel by heating it just above its critical temperature and slowly cooling it down. Above this range the coarse crystalline structure which previously existed is entirely obliterated, due to the iron and iron carbide going into solid solution, in exactly the same manner as was described in connection with the dead soft annealing of low carbon wire.

The effect of overheating in coarsening the grain structure of a .45 per cent carbon steel and the refining influence of this type of annealing is shown in Figs. 5 and 6.

FIG. 5.—Steel, .45 carbon, overheated. × 100.

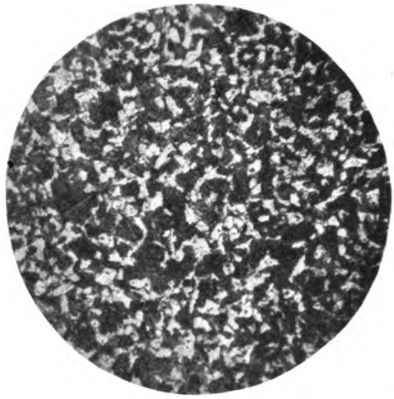


FIG. 6.—Steel, .45 carbon, annealed. × 100.

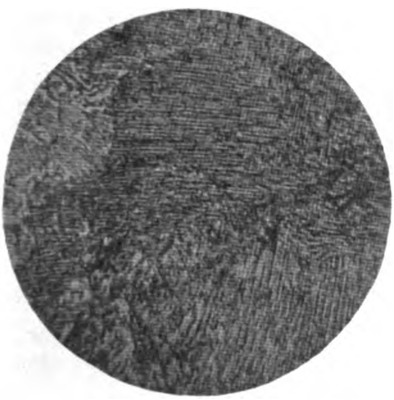


FIG. 7.—Steel, .85 carbon, annealed. × 1000.

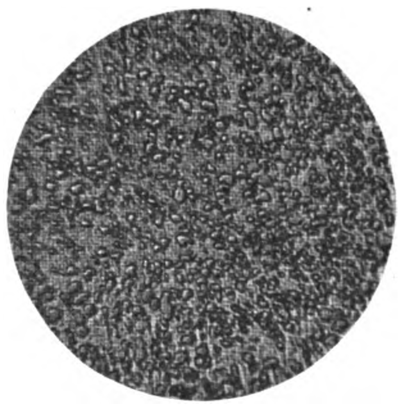


FIG. 8.—Steel, .85 carbon, annealed for globular structure. × 1000.

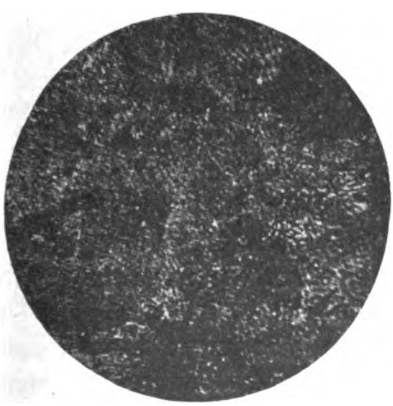


FIG. 9.—Steel, .85 carbon, patented. × 1000.

Creating Definite Structure by Annealing.

The third and last class of annealing to be described—that to obtain definite structure—is one of comparatively recent development in the steel wire industry and one which promises to be of considerable value. It is now well known that the mechanical properties of a wire depend in great measure upon the structure of the material, and that it is beyond the scope of chemical analysis to reveal a knowledge of structure. The workability, so to speak, of a wire for certain purposes is primarily dependent upon a physical condition of the steel. It becomes apparent, therefore, that through the use of heat treatment scientifically applied and controlled there is opened a field of unusual opportunity. In this line very little could be done prior to the application of the microscope and pyrometer to the study of the practical problems of wire manufacture.

It cannot be said that the use of these instruments led to the discovery of anything new in the way of heat treatment processes; nor did they create new fields for the employment of wire. They do accomplish, however, two important things: (1) The making of a product of higher quality than had hitherto been the case, by supplying a material of superior structure for the purpose, and of greater uniformity than could possibly have been the case under less intelligent direction in manufacture; and (2) the placing of the manufacture of such materials in the wire mills on a scientifically improved basis, with fewer rejections and consequently with less cost to the user. Today a wire problem essentially involving structure is first studied under the microscope until the structure giving the best results is found. After that, by means of the pyrometer and other improved facilities of the present up-to-date wire mill, it is a simple matter to see that the heat treatment necessary to supply the desired structure is employed in the practical manufacture of the wire.

Annealing of the type under discussion is applied principally to the higher carbon wires. Since the structure of such wires can be varied considerably within a small

range of annealing temperatures, it covers specific products and not general classes, as would be the case in regard to the two previously described types of annealing.

Figures 7 and 8 illustrate excellently this special type of annealing. These photographs show the structures of two annealed pieces of the same coil of high carbon wire, in which the annealing temperature of the one specimen was 1300° F., and of the other 1250° F. It is impossible to identify the structure by a simple observation of the fracture, which is the ordinary rough and ready method; nor is it possible to regulate annealing temperatures so closely without the use of pyrometers.

THE PRACTICAL SCOPE OF PATENTING.

In passing to the next great class of heat treatment applied to steel wire, Patenting, it is interesting to note that we likewise pass to another class of wire as regards grading by carbon content. As has been previously pointed out, annealing covers primarily the lower carbon steel wires, with special and restricted application to the medium and higher carbon steels, while patenting naturally covers the medium carbon steels, being employed chiefly on carbons between .35 and .85 per cent. In low carbon wires, softness and ductility are the qualities desired both in order to facilitate the working of the metal, and, except in the case of hard drawn wires, in order to make the finished material of commercial and practical value. In the medium carbon steel wires, on the other hand, strength and toughness are required for both process and finished wire. Patenting makes possible this combination of strength and toughness, and to this process is due in large measure a broad field of application for steel wire.

Classes of Products Patented.

From a tonnage standpoint, wire rope is the most important product of this class of heat treatment. In some respects it is the most important from a quality view-point,

for the reason that in the manifold uses of wire rope the safety of human life is of vital consequence. There are also economical considerations relative to the handling of enormous tonnages at low cost, of which there is no better illustration than that furnished by the steel industry itself in the mining, loading and handling of tremendous quantities of ore and coal.

It should be appreciated, of course, that it is not within the power of patenting or any other heat treatment to make the proverbial "silk purse out of a sow's ear," for the best results in any steel product require the proper quality in the steel itself and proper treatment at every stage of its manufacture. However, in the manufacture of good rope wire it is possible through improper patenting to make the converse true, and produce a sow's ear from a silk purse. There is probably no feature of the wire business that has been given more scientific study than the heat treatment of rope wire. Rates and degrees of heating and cooling have been standardized to such an extent through the use of the microscope, pyrometers, and testing instruments, that a degree of uniform quality is reached that previously was impossible.

Another important class of wire dependent for its superior quality upon the patenting process is music wire for pianos and other stringed instruments. In order to have tone and hold pitch music wire must possess extremely high tensile strength and must also have suitable physical properties to enable it to be applied in the instrument. By a proper combination of drafting and patenting it is possible to obtain music wire from a .70 per cent. carbon steel which will have a tensile strength of 400,000 pounds per square inch, and be sufficiently tough to be wrapped about itself without breaking, and be swaged flat to one-half its original thickness without splitting. Through this remarkable combination of properties, which in steel are usually antagonistic, music wire may justly be said to represent the highest development in the manufacture of wire. Without the patenting process as we know it to-day, it would be impossible to produce wire of such characteristics.

The Structure of Patented Wire.

The high strength and toughness of patented wire are due to its carbon condition and to its peculiar structure. The first step in the patenting process is to heat the wire to a temperature above its critical range. As previously explained, when steel is heated above its critical temperature the iron and iron carbide go into a solid solution. This, of course, causes the carbide of iron to become homogeneously distributed. In patenting, the degree of heating is regulated according to the carbon content of the steel, the size of rod or wire, and the time the material is subjected to the heat. After sufficient heating, the next step is to cool the material rapidly below its critical range, the structure obtained depending upon the rate of cooling. In practice, patenting is usually conducted as a continuous operation, the wire being led through the heated tubes of a furnace and cooled by being brought into the air or into a bath of molten lead comparatively cool but seldom under 700° F.

A better understanding of the structure of a patented wire may be had by a comparison of the structure obtained by slow and by rapid cooling. If the steel after being heated is allowed to cool slowly through the critical temperature range, the homogeneous pre-existing solid solution of iron and iron carbide separates into a heterogeneous mixture of two constituents, resulting in the plate-like structure called "pearlite," in which, as described previously, iron and iron carbide arrange themselves independently in alternate thin plates. In the patented wire structure, on the other hand, the cooling through the critical temperature range is too rapid to permit the separation of the iron and iron carbide into this plate-like structure. In a patented wire, part of the carbide of iron is in solid solution and the remainder, while not in solid solution, has not had time to form into plates. The difference in structure between slow and rapid cooling is seen in Figs. 7 and 9.

The photomicrograph of the patented wire shows, as a result of the rapid cooling, a structure that might be termed nondescript. Metallographists will recognize the structure

as "sorbite," which, in the cooling of the higher carbon steels from above the critical temperature, is that stage of transition just preceding the pearlitic, the final condition of annealed steel as shown in Fig. 7. The patented wire, therefore, represents an unsegregated condition as against the segregated or coarsely laminated structure of annealed wire. The high tensile strength of patented wire is due to the amount of carbon in solution, and its toughness to the fineness of the grain structure.

Functions of Patenting.

Patenting serves two important functions in the wire business: (1) In the process of manufacture, the removal of the effects of cold work, such as drawing. (2) In the finished wire, to give in conjunction with cold drawing, the required combination of strength and toughness.

The effect of wire drawing on medium and high carbon wires is similar to that previously described in connection with low carbon wires. The structural grains lengthen out in the wire drawing process, and patenting is resorted to as conditions demand to relieve the strain before the limit of ductility of the grain structure is exceeded. Strictly speaking, patenting is not necessary simply to relieve strain, for annealing would serve that purpose, but the structure obtained by patenting permits much further cold drawing than does the structure obtained by annealing. This is due primarily to the increased ductility and toughness of the patented wire. The effect of patenting as just described, is shown in Table B and Charts II. and III.

Table B represents typical practice in manufacturing a certain wire of .50 per cent. carbon steel from a No. 5 gauge (.207 in.) rod to a finished size of .02 in. The rod in question as it came from the rolling mill had a tensile strength of 95,000 lbs. per sq. in. and an elongation of 10 per cent. After the first draft of 28½ per cent., there is an increase in tensile strength of 27,000 lbs. per sq. in., and the elongation is reduced to 2.9 per cent. After the first patenting of the wire it has a tensile strength of 115,000 lbs. per sq. in. and an elongation of 8.2 per cent. It is then subjected to 4

drafts, being thereby reduced 65 per cent. from the first patenting point before the second patenting is necessary.

After the second patenting, the wire has a tensile strength of 128,000 lbs. It is then drafted 76 per cent. further before the final patenting, which leaves the wire with a tensile strength of 156,000 lbs. The properties of the finished wire depend largely upon this last patenting and the subsequent drawing to the finished size. In the case in question the wire was drawn 3 drafts and reduced 66 per cent. from the last patenting size, ending at finished size with a tensile strength of 218,000 lbs. It will be noted that the tensile strength of the wire immediately after patenting is higher as the size of wire decreases. This is due to the fact that in practice the smaller the wire the more quickly it cools, and consequently the greater the amount of carbon in solution. This, as explained previously, is the condition of a patented wire that makes for its strength.

In Table B and the note thereto are given the corresponding tensile strength and elongation of the same wire when patented and when annealed. It will be seen that the tensile strength of the annealed wire is 70,000 lbs. per sq. in. as against 115,000 lbs. per sq. in. of the patented wire. This is due to the fact that, on account of the comparatively slow cooling in annealing, none of the carbon of the steel is in solution. It might be supposed that, owing to its being softer and of higher elongation, the annealed steel would withstand a further degree of drafting than the patented steel. On the contrary, however, on account of the rapid loss of ductility characteristic of the annealed wire structure, the annealed structure will not withstand drawing to anywhere near the same degree as will the patented structure. Generally speaking, the patented wire structure has more than twice the ductility of the annealed.

Chart II. shows graphically the increase of tensile strength in cold drawing from a rod of .50 per cent. carbon steel, wire .02 in. in diameter and the effect of patenting in removing the results of the cold work. It indicates also the importance of the patenting process in creating a structure that permits an increase, by heavy drafting, of 50,000

lbs. per sq. in. in tensile strength, and leaves in the finished wire a remarkable degree of toughness rather than brittleness. Incidentally, it may be noted from this chart that

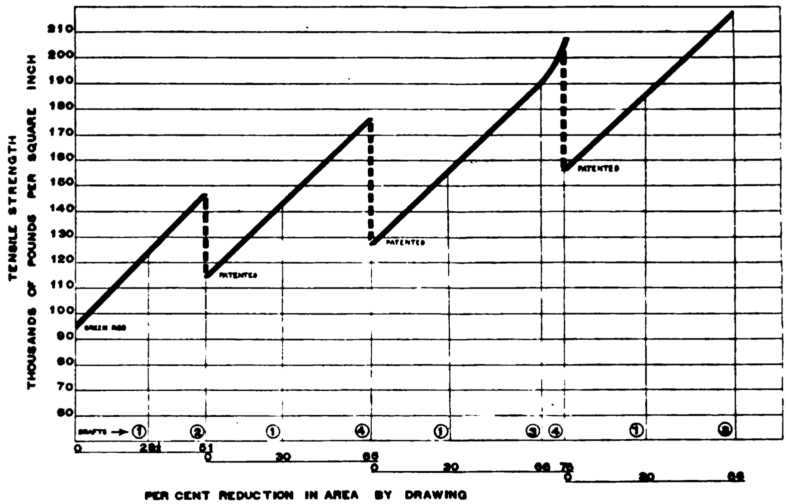


CHART II.—Showing the increase of tensile strength due to drawing, and the effect of patenting, medium carbon (0.50 per cent.) steel.

the same regular increase in tensile strength, due to drawing, is characteristic of the higher carbon steels as of the lower carbon steels previously shown.

OBTAINING HIGH TENSILE STRENGTH.

Chart III. shows a typical practice in obtaining a tensile strength of 375,000 lbs. per sq. in. in a music wire .03 in. diameter from a patented rod .192 in. in diameter, of .70 per cent. carbon. It indicates the marked increase in tensile strength from the last patenting point, and emphasizes the remarkable character of a wire of such strength possessing the workable properties necessary for music wire. It will be seen that from the last patenting point the wire is reduced about 94 per cent., i.e., elongated 18 times its length, and to do this on the wire in question, 19 drafts were taken. The increase in tensile strength per sq. in., due to this heavy drafting, amounts to about 200,000 lbs. from the last

patenting point. In the final drafts there is an enormous increase of tensile strength. In fact, as the curve shows, a certain reduction towards the end increases the tensile

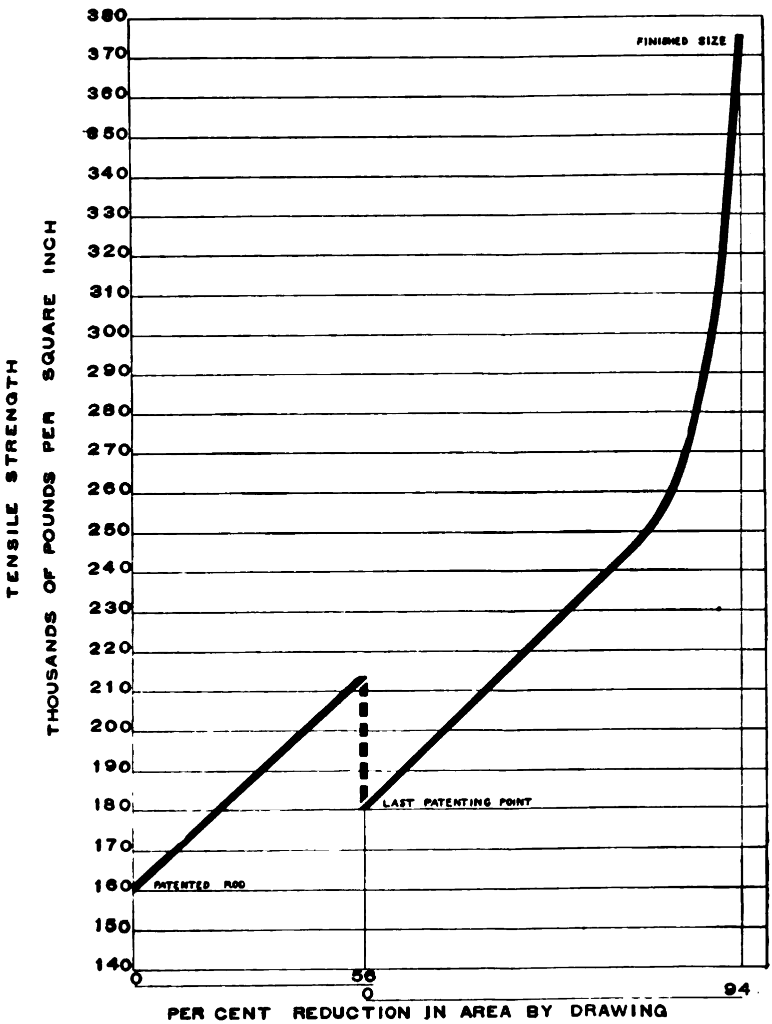


CHART III.—Showing the process for producing .03-inch wire (0.70 per cent. carbon) having a tensile strength of 375,000 lbs. per sq. in.

strength much more than an equal reduction near the patenting point. One might think a wire made according to the above practice would be as brittle as a clay pipe stem;

but, on the contrary, it is singularly tough, and stands wrapping, bending and flattening to a truly remarkable degree.

PRACTICAL SCOPE OF HARDENING AND TEMPERING.

We have now come to the third class of heat treatments applied to steel wire—hardening and tempering—processes which affect not only a large tonnage but an extensive variety of wire. The principal commercially important grades of wire dependent upon hardening and tempering are clock and watch spring, typewriter, motor and door check spring, umbrella, dress stay, knife blade, razor blade, measuring tape, band saw, hack saw and curtain spring wire, all of which are heat treated as wires. There is, moreover, still further a large field of use for wires which are hardened and tempered after being formed into springs, tools and miscellaneous special products.

Hardening and tempering is probably of broader commercial importance and application than any other type of heat treatment given to high carbon steels. In the past fifteen years it has been given tremendous impetus by the growth of the automobile business and the increased use of alloy steels. Furthermore, the commercial value of this class of heat treatment of steel has been appreciated and emphasized in recent years in practically all lines of manufacture and use of steel products.

Outside of the manufacture of wire, hardening and tempering are usually separate and distinct operations. But in wire the two terms always go together, there being practically no field of usefulness for wire simply hardened. It naturally follows, therefore, that in wire making, hardening and tempering should be conducted usually as a continuous process. In the making of tempered wire, the material is first run through the heated tubes of a furnace, then quenched quickly in a bath of oil or water, then run into the tempering bath of, say, molten lead, each wire being in continuous motion from the time it enters the heating furnace until it is

wound on a reel. Such wire products as springs made of untempered wire, hardened and tempered after forming, do not of course, have the several steps conducted as a continuous process, but there is no difference in essential principles.

In the development of the subject matter of this paper, for the purpose of associating readily the various classes of wire with the several heat treatments, annealing has been shown to cover primarily the low carbon steels, and patenting, the medium carbon steels. Hardening and tempering apply to the higher carbon steel wires—those in which the carbon range is from .65 per cent. to 1.00 per cent.

The Process of Hardening and Tempering.

In hardening wire the first step is identical with that previously described for patenting, and is accomplished in practically the same manner. That is, the wire is heated above the critical temperature to enable the iron and iron carbide constituents to go into solid solution before quenching. After quenching, the steel, on account of its sudden cooling through the critical temperature, is hard and brittle. Cooling in this manner is too rapid to permit the segregation of the constituents, iron and iron carbide; and, as a result, considerable of the carbon content is in solid solution, the amount depending upon the total carbon in the steel and the rate of cooling. In the discussion of patenting it was pointed out that carbon in solution causes hardness in the wire. It will be apparent that in hardening, as above defined, the amount of carbon held in solution will be much greater than in the patenting process, due to the much more rapid rate of cooling through the critical temperature, secured by the use of a quenching bath of low temperature. The structure thus obtained in the hardened wire depends on the rate of cooling. Small sections will be "martensite" —containing most of the iron carbide in solution; larger sections will be "troostite"—containing less iron carbide in solution; still larger sections will be "sorbite"—containing still less iron carbide in solution.

Besides martensite, troostite and sorbite, there are many intermediate "transition structures" formed by the different

cooling rates of sections of different sizes. The hardened material contains more iron carbide in solution than is desired in the finished hardened and tempered wire, that is, the hardened wire is harder than is desired. The hardness is finally lowered to the desired degree or "temper" by carefully adjusting the temperature of the "tempering" bath.

It will be apparent from the foregoing that hardening and tempering are of a contradictory nature as separate treatments, the hardening operation creating an excessive hardness which the tempering operation reduces to the proper degree, dependent upon the use to which the material is to be put.

This process of hardening and tempering, simple as it appears is, in practice, the most complicated in principle of any of the heat treatments described, and demands great accuracy of temperature control to secure the fine shades of temper demanded by the multiplicity of uses to which the finished product is applied by the consumer.

Functions of Hardening and Tempering.

Since the hardness and brittleness of wire simply hardened are such as to make it practically useless for commercial purposes, the effect of the tempering process is to remove some of the brittle hardness from the steel and to toughen it. The efficacy of tempering is due to the fact that hardened steel is apparently in an unstable condition and seems ready on slight provocation to return to a stable form. When hardened steel is subjected to even a low tempering heat, the carbide in solution tends to separate out. It follows that the higher the tempering heat the greater will be the amount of iron carbide released from solution, and the lower will be the hardness or "temper" of the finished product. At a tempering temperature of 1250° F. even a hardened .90 per cent. carbon wire will lose practically all its hardness and be virtually in an unhardened condition.

Temperatures Employed in Tempering.

In tempering wire for the greatest desired hardness, the temperature of the bath may be as low as 400° F. Tem-

pering heats between this and 1200° F. give practically any desired hardness. In passing it may be stated that the field of commercial tempered wire requirements is such as to necessitate a wide range of temperature on the various quenching baths in the tempering room of a wire mill.

In general, the reheating incident to tempering is usually considerably below the critical temperature.

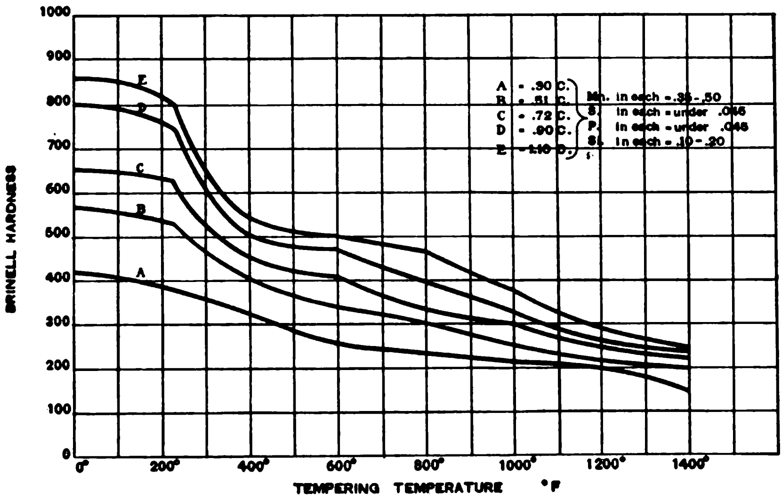


CHART IV.—Showing loss of hardness due to tempering steels of various carbon content.

Chart IV. shows the loss of hardness due to tempering carbon steel at varying temperatures. The horizontal distances represent the tempering temperature, and the vertical distances the hardness by the Brinell test. The plotted curves are based on actual tests of spring stock of practically the same analysis and grade of steel as regards manganese, sulphur, phosphorus and silicon, while the carbons vary from .30 per cent. to 1.10 per cent.

It will be noticed that there is a marked loss of hardness on all wires tested between the temperatures of 200° F. and 600° F., the most marked loss being between 200° F. and 400° F., and that the higher the carbon the greater the loss of hardness, especially at the lower temperatures. Furthermore, it will be seen that at 1300° F. the hardness of all the samples is practically the same, irrespective of carbon con-

tent. In fact, at this temperature even the highest carbon wire shown is relatively soft and ductile and may be drawn several drafts. Thus is it possible to obtain in any steel, within the limits imposed by its carbon content, any desired temper, whether it be extremely high or correspondingly low.

Of the various classes of hardened and tempered wires, razor blade represents the highest temper, band saw and corset wire the medium temper, and spring wire the relatively low temper.

Effect of Tempering on Tensile Strength.

Chart V. gives the tensile strength of a hardened .70 per cent. carbon wire at various tempering temperatures, from

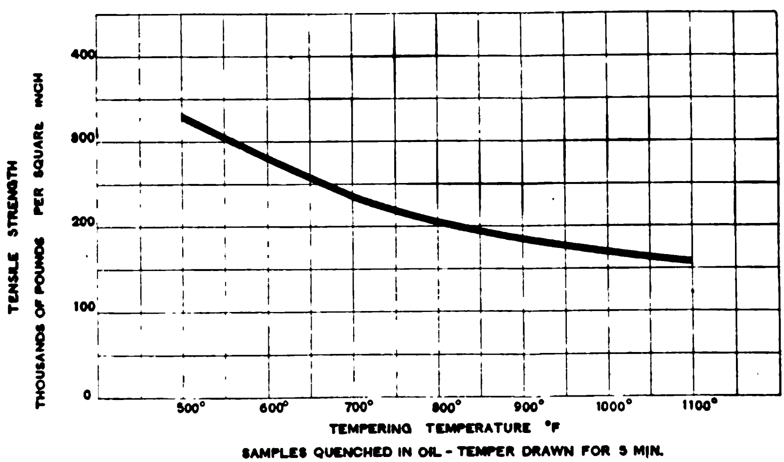


Chart V.—Showing the effect of the tempering temperature on the tensile strength of 0.70 per cent. carbon hardened wire (diameter .080 in.)

which the marked effect of tempering in affecting physical properties will be evident. With varying tempering temperatures between 500° F. and 1100° F., the tensile strength runs from about 340,000 lbs. per sq. in. to 150,000 lbs. per sq. in. At the lower temperature the decrease in tensile strength is, as we should expect, much greater per 100° F. range than at the higher temperatures. From 500° F. to 600° F. there is a drop of 60,000 lbs. per sq. in.; while be-

tween 1000° F. and 1100° F. the drop in tensile strength amounts to only about 10,000 lbs. per sq. in.

CONCLUSION.

From the foregoing discussion of the several heat treatments of importance in the wire business it will be apparent that at the basis of the industry there are certain fundamental laws which govern all processes in the manufacture of steel wire, whether it be cold treatment incident to drawing or heat treatment incident to the various operations described herein. Like all natural laws, those governing the behavior of steel in the manufacture of wire are inexorable, and the results obtained depend primarily upon the determination of those laws and upon their proper recognition and consideration in actual practice. Herein lies the reason for the vast difference between wire mill practice of the past and that of the present. The heat treatments which are applied to-day with such beneficial results were known then, but the underlying laws governing them were not. The scrap and rejections in the wire mill, the lack of uniformity and the unsuitable quality of the product, and the complaints of customers were all too frequently ascribed to the "devil in the steel." With the establishment in the past few years in our colleges of broader courses for the study of the nature and behavior of steel, and the resultant advent into the steel business of technically trained young men, and with the establishment of laboratories for the study of practical steel problems, with their invaluable aids in the shape of the microscope and the pyrometer, there has been given an impetus to a development in the steel wire business that has been unprecedented. The present day wire mill, with its hundreds of pyrometers and automatic temperature regulating and recording apparatus, gives silent but forceful testimony to the passing of the old type of "practical" man whom Professor Sauveur has described as "the industrial Philistine clumsily standing in the way of scientific applications to industrial operations."

In the works with which I am associated, a physical

laboratory for the study of heat treatments and other metallurgical problems connected with the manufacture of high grade wire was established several years ago. A convincing proof of its practical value lies in the fact that the facilities for carrying on this work have been steadily increased. Today we have a large force of technically trained men in this laboratory, a costly and extensive equipment, and a separate building devoted entirely to the work.

Our physical laboratory is in every sense a practical and efficient adjunct to our producing department. Of fundamental importance in the practical application of the work of a laboratory of this kind, is the training of the men carrying on the work. To make their work of the greatest value, these men should be more than merely technically trained. We believe that the excellent results we have obtained in the heat treatment of wire are due in large measure to the fact that our laboratory men, in investigating a problem, study first all the conditions pertaining to the uses to which the product is to be put by the customer, and follow personally all investigations and experiments in the works' processes bearing on the subject.

In this way our laboratory men are made to recognize practical conditions, while our workmen become thoroughly trained as to the problem and the methods adopted for its solution. Thus, we have found it possible to overcome prejudice which the practical man often has for "theory," and to establish in its place a spirit of eagerness for better practice.

The results already obtained warrant us in feeling that there is ahead of us abundant opportunity for making steel of even greater value in the service of mankind.

THE PRACTICAL IMPORTANCE OF HEAT TREATMENTS IN THE STEEL WIRE INDUSTRY

JAMES W. SMITH

Factory Manager, The Wyman & Gordon Company, Worcester, Mass.

It is a pleasure to add a few words to the interesting and thoroughly practical paper presented by Mr. Tinsley.

From an intimate connection with the steel wire industry for a number of years, I fully recognize the importance of heat treatment to that industry, and the improvement both in output and in quality of products from mills where heat treatment has been given scientific and systematic study.

The products of the works with which I am now connected are drop forgings. In this work most exacting physical and chemical requirements are specified. To those handling steel products to meet rigid specifications, it is well known that heats of identical analysis and other results of examinations of the steel itself in regular common practice laboratory methods will not always produce the same physical qualities under the same heat-treating and working conditions. In addition to this, the various steels are so sensitive to heat treatment that to obtain the uniform high standard products required it has been found necessary in these works to establish the system of making a preliminary investigation and heat-treating standard for every heat of steel received and before any of the same is put into process of manufacture.

To accomplish this a thoroughly equipped chemical, physical and metallographical laboratory is maintained. The force employed in this laboratory, in addition to their investigation work, are constantly kept in intimate contact with the heating and heat-treating work at all stages of the forging process. Our experience has proven the practical application of such a laboratory in that manner to be of the first importance.

Formerly it was necessary to measure steel treating temperatures with very crude instruments, such, for example, as that of the determination of the proper temperature of a lead bath by the immersing of a dry pine stick in the bath for a certain number of seconds and establishing the temperature by the appearance of the charred portion of the stick.

Proper heat treatment requires the use of accurate temperature-measuring instruments, and with the development of pyrometer manufacture in recent years accuracy along this line is now obtainable.

Assuming the use of an accurate temperature indicator, it is vital that the stock under treatment shall be at the temperature desired and as indicated by the pyrometer. Particular mention is made of this point because in many cases where careful heat treatment has been attempted and the desired result has not been obtained, temperature-measuring instruments have registered the temperature of the medium surrounding the stock, which is not necessarily the same as the temperature of the actual stock by a considerable amount.

The rapid change of structure and physical properties with the different temperatures within the usual heat-treating range of approximately 1300° to 1700° Fahrenheit for hardening and 800° to 1200° Fahrenheit for drawing, is shown on the microphotographs herewith. Each Figure (pages 157 and 159) is illustrated by two microphotographs, of which the first has a magnification of 100 and the second a magnification of 600.

Fig. 1 shows the structure of the steel after being quenched at a temperature of 1300° F. and annealed at 1090° F. The structure is seen to be coarse and to consist entirely of pearlite (the darker constituent) and ferrite (the lighter constituent). The ferrite and pearlite are the two softest constituents which steel can have, and will be found in all forged or rolled and slowly cooled carbon steel. The critical range of this steel is about 1425° F. As we did not exceed 1300° F. on our quenching temperature, practically no change has taken place in the structure of this steel by

FIG. 1.

Hardened at........1300° F.
Drawn at. ....1090° F.
Elastic Limit.......38,750 lbs.
Ultimate Strength...82,750 lbs.
Elongation in 2 in...26.5%
Reduction of Area...43.0%

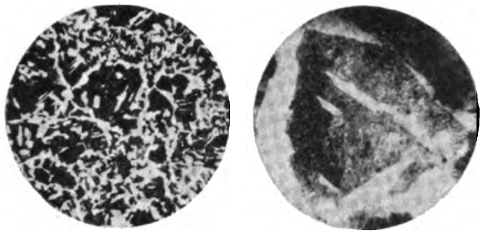


FIG. 2.

Hardened at........1400° F.
Drawn at..........1090° F.
Elastic Limit.......49,250 lbs.
Ultimate Strength..94,500 lbs.
Elongation in 2 in...19.5%
Reduction of Area...44.8%

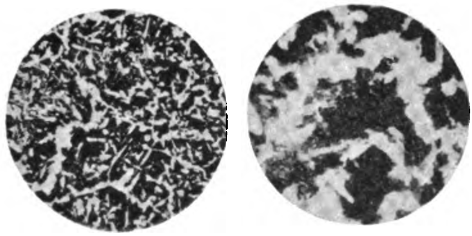


FIG. 3.

Hardened at.... ...1520° F.
Drawn at..........1090° F.
Elastic Limit....... 77,500 lbs.
Ultimate Strength..107,250 lbs.
Elongation in 2 in...21.8%
Reduction of Area...58.8%

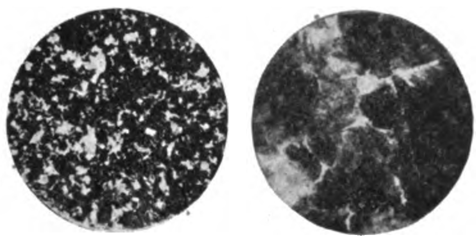


FIG. 4.

Hardened at........1600° F.
Drawn at..........1090° F.
Elastic Limit....... 75,000 lbs.
Ultimate Strength..111,250 lbs.
Elongation in 2 in...21.0%
Contraction of Area.53.7%

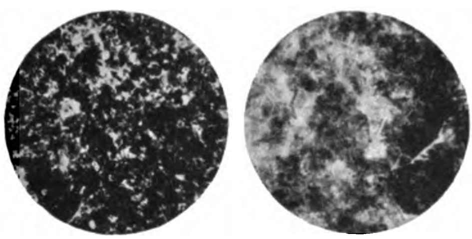


FIG. 5.

Hardened at........1725° F.
Drawn at..........1090° F.
Elastic Limit....... 80,500 lbs.
Ultimate Strength..119,500 lbs.
Elongation in 2 in...17.1%
Reduction of Area...45.4%

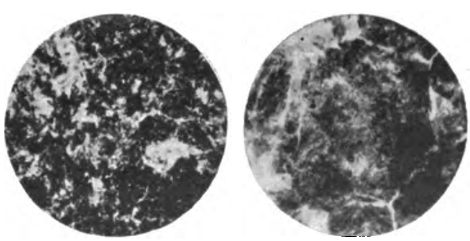
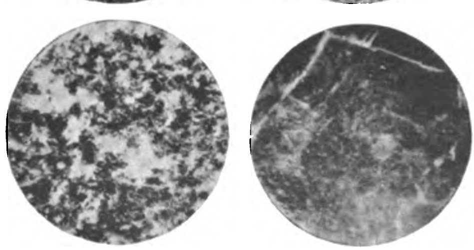


FIG. 6.

Hardened at........1800° F.
Drawn at..........1090° F.
Elastic Limit....... 86,750 lbs.
Ultimate Strength..114,750 lbs.
Elongation in 2 in...17.1%
Reduction of Area...41.2%



this heat treatment from its properties when in a forged condition.

Fig. 2 shows the steel quenched from 1400° F. and annealed at 1090° F. We find some change has taken place. The dark constituent in the first set of pictures, the so-called pearlite, still remains dark in color, but it has now changed into a new constituent called "sorbite." That this new structure differs from the pearlite of the first set may easily be seen on comparing the higher power photographs, where it will be noticed that the laminated structure of the pearlite has entirely disappeared. The white constituent still remains the same, the free ferrite. The sorbite combines at the same time the greatest hardness and percentage of reduction of area of all the constituents of steel, and is the structure most sought for in parts that require a high elastic limit combined with a large reduction of area. In this case, we see that the temperature of quenching is high enough to harden up all the pearlite, but not high enough to make the excess ferrite dissolve in the sorbite. In other words, the piece was quenched when in the critical range of temperature and not when above it.

In Fig. 3, showing the steel quenched at 1520° F. and drawn to 1090° F., we find a marked change. Here the entire structure consists of sorbite, except for a very small amount of free ferrite, which is nearly always present in treated pieces of this cross-section. In this case the piece was heated above its critical range and everything driven into solution, forming the so-called solid solution. When quenched, this was retained mostly as martensite, and upon drawing this broke down into the sorbite, which is so much desired. We may consider Figs. 4 to 6 together. It will be noticed that the structure in all still remains sorbitic but the grain size is best shown in the higher magnifications, increasing very markedly as we increase the hardening temperature.

Figs. 7 to 12 show the steel hardened at the same but drawn at different temperatures. From Figs. 1 to 6, which we have just seen, it is observed that the grain size is governed by the quenching temperature, and since in Figs. 7

FIG. 7.

Hardened at........1550° F.
Drawn at.......... 900° F.
Elastic Limit....... 85,500 lbs.
Ultimate Strength..127,250 lbs.
Elongation in 2 in...18.7%
Reduction of Area...45.1%

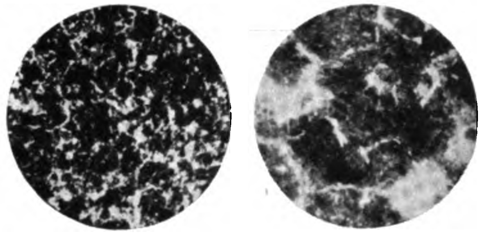


FIG. 8.

Hardened at........1550° F.
Drawn at..........1020° F.
Elastic Limit....... 80,500 lbs.
Ultimate Strength..115,500 lbs.
Elongation in 2 in...20.3%
Reduction of Area...51.9%

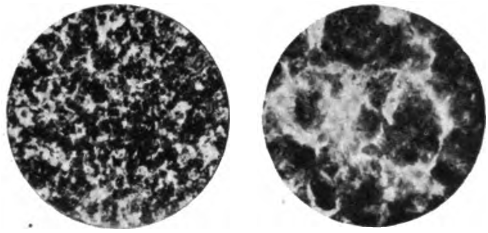


FIG. 9.

Hardened at........1550° F.
Drawn at..........1100° F.
Elastic Limit....... 75,250 lbs.
Ultimate Strength..114,000 lbs.
Elongation in 2 in...21.0%
Reduction of Area...52.2%

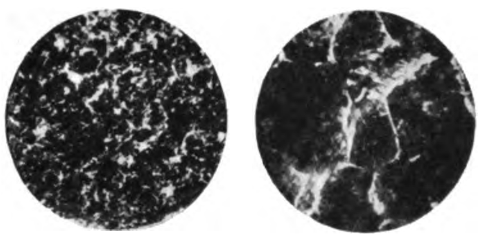


FIG. 10.

Hardened at........1550° F.
Drawn at..........1200° F.
Elastic Limit....... 69,500 lbs.
Ultimate Strength..104,250 lbs.
Elongation in 2 in...24.2%
Reduction of Area...58.5%

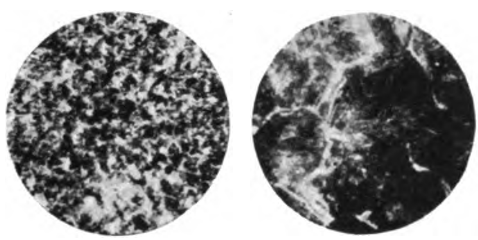


FIG. 11.

Hardened at........1550° F.
Drawn at..........1300° F.
Elastic Limit.......63,500 lbs.
Ultimate Strength..95,000 lbs.
Elongation in 2 in...28.6%
Reduction of Area...62.0%

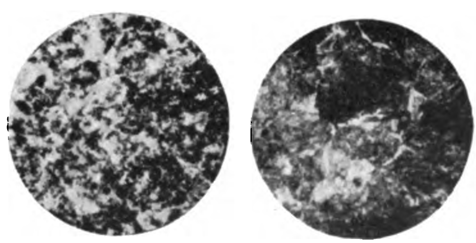
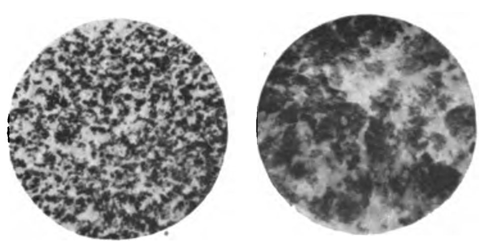


FIG. 12.

Hardened at........1550° F.
Drawn at..........1400° F.
Elastic Limit.......53,000 lbs.
Ultimate Strength..82,750 lbs.
Elongation in 2 in...23.4%
Reduction of Area...60.3%



to 12 the steel was all quenched from the same temperature, we should expect the grain size to be the same throughout. This is the case with the exception of the last one (Fig. 12), which was drawn at 1400° F. In this case, the drawing temperature was at the beginning of the critical range, and we see the sorbite breaking up to form finally the pearlite and free ferrite with which we started. In all other cases, we have a structure consisting mainly of sorbite, with small amounts of free ferrite.

In the next two diagrams (Figs. 13 and 14) are shown graphically the variation of ultimate strength, elastic limit and reduction of area, at the same temperatures shown by the microphotographs just previously referred to.

The widely varying physical properties shown by these charts with changes of 100° only in temperature emphasize the importance of the two points previously referred to, namely, the use of accurate temperature-indicating instruments and the certainty that the stock which is undergoing treatment is at the temperature desired and as registered.

By heat treating alone, forgings with an approximate cross sectional area of four square inches, for example, are in .50 carbon steel regularly given the following physical properties:

Tensile strength	112,000 lbs.
Elastic limit	77,000 lbs.
Reduction of area	52%
Elongation	17%

In nickel chrome alloy steel with carbon content .40, nickel 1.25, chrome, .70, the following physical properties are produced:

Tensile strength	135,000 lbs.
Elastic limit	116,000 lbs.
Reduction of area	53%
Elongation	17%

In both of these cases the steel is in a perfectly machinable condition.

VARIATION IN PHYSICAL PROPERTIES OF MEDIUM CARBON STEEL
DRAWN AT 1090 °F AND HARDENED AT VARIOUS TEMPERATURES

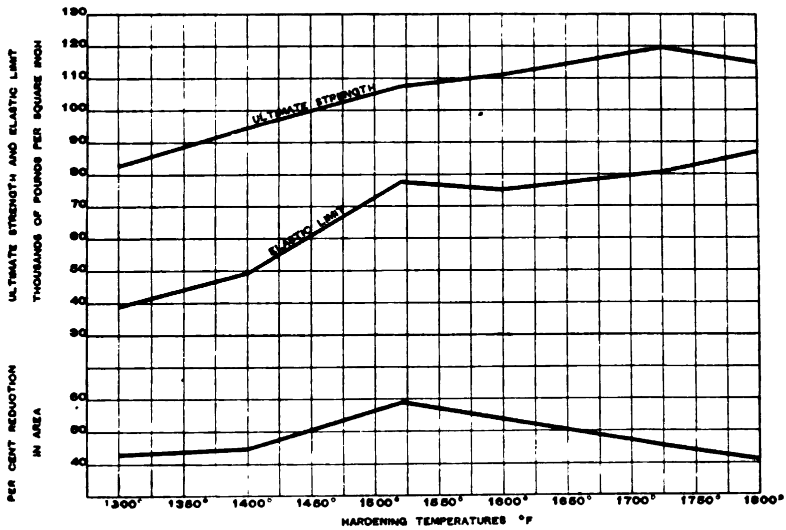


FIGURE 13

VARIATION IN PHYSICAL PROPERTIES OF MEDIUM CARBON STEEL
HARDENED AT 1550 °F AND DRAWN AT VARIOUS TEMPERATURES

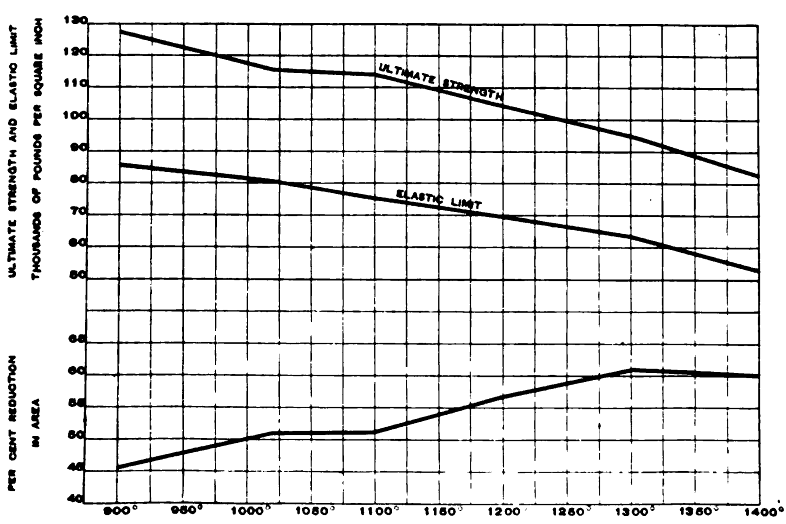


FIGURE 14

Depending upon the use to which a wire may be put, a simple carbon steel wire with carbon content .55 to .60 can be patented and drawn after patenting to a size having the following physical properties:

Tensile strength.......220,000 lbs.
Elastic limit..........121,000 or 55% ult. strength

This same wire of the same finished size and same physical properties as given can be double heat treated, that is, tempered and drawn to the following physical properties:

Tensile strength.......220,000 lbs.
Elastic limit..........189,200 or 86% ult. strength

These figures show an instance of widely different physical properties in two wires of the same size and identical analysis due to manipulation, that is, heat treatment as combined with cold drawing in the one case, and heat treatment alone in the other.

With the opportunity for the combination of heat treatment and subsequent cold working, rapid changes and advances must be made in wire structures, resulting in highly improved physical properties.

TRANSPORTATION

J. Fred Townsend

Traffic Manager, National Tube Company, Pittsburgh, Pa.

Transportation is a problem that we are all more or less familiar with, and I will not attempt to deal with its early forms, such as the conestoga wagon, canal, and river craft, but shall confine myself to the chief means of conducting transportation at the present time, the railroad.

American Railroad Development.

Let us consider for a moment the American railroad development. Rapid strides have been made during the last decade in rehabilitating the property generally—reduction of grades, eliminating the curves, reconstructing the roadbed, replacing bridges and structures with larger and stronger material, and laying heavier steel rails, to care for the motive power and rolling stock that has been doubled in capacity, building second and third tracks and making extraordinary improvements in terminal yard facilities.

About thirty-five years ago, the maximum freight carload was 24,000 pounds. The New York, Chicago & St. Louis Railroad was constructed at that time. It was built and equipped upon the most advanced ideas, which prompted some one to suggest its popular name, "Nickel Plate," and its new freight cars were all of 40,000 pounds capacity. This car would carry nearly double the load of the cars then generally in use.

All railroads throughout the country commenced enlarging their equipment, and during the next ten years the 50,000- and 60,000-pound-capacity cars appeared. To-day we have the 100,000- and the 140,000-pound-capacity cars, and it would be hard indeed to convince some people that the limit has not been reached.

However, when such a bulky commodity as coke can be loaded to the highest limit in the modern freight car, i.e., to 10 per cent. above marked capacity in the 100,000-pound cars, it would seem to a layman that the unit of

transportation should be increased, and instead of going through the slow and expensive changes of raising the limit 10,000 or 20,000 pounds at a time, a 200,000- or a 300,000-capacity car should be adopted.

Transportation is King.

Half a century ago there was a saying, "Cotton is King." Later we were taught that steel was "king" and that any fluctuation in the steel market was immediately reflected in other lines of business. Others claimed that grain was "king," and pointed with pride to the bumper crop years. Even to-day some are predicting a great revival in business as soon as the crops are harvested, on the theory that good crops and good times always travel together.

How long would any of these kings rule if it were not for the real king, Transportation, that makes it possible to assemble the raw materials at convenient points where blast furnaces, flour mills, or other manufacturing plants are located and the products of the earth are transformed into merchantable articles, to be again turned over to the transportation lines to be moved to the markets of the world?

Thirteen years ago, or shortly after the United States Steel Corporation was formed, President Schwab brought this question before the traffic managers in a very forceful manner by making the statement that there were three items of cost: First, the raw materials; second, labor; third and last, but not least, transportation.

Steel's Contribution to Improved Transportation.

What have the steel producers done to improve transportation during the period referred to? There can be no question but that the most remarkable progress has been made in the reconstruction of manufacturing plants, increasing production and decreasing cost of operation. In the tonnage of Pittsburgh alone in thirteen years this has resulted in an increase of 107,589,450 tons. This seems almost unbelievable, but the actual figures compiled for the railroad tonnage alone of the Pittsburgh District for 1900, was 57,005,465 tons, while for 1912, it was 164,594,915 tons,

an increase of 189 per cent. To handle this enormously increased tonnage, there has been a continual struggle to get sufficient cars to keep the mines and mills supplied.

During this period, the steel producers have doubled and trebled the size of ships on the lakes and increased the capacity of dock machinery for the more rapid and economical transportation of ore. And it seems to me the railroads' opportunity to increase their net revenue irrespective of increased wages and expenses is here, and that they can accomplish this by following the example of the iron and steel manufacturers in increasing their facilities and then making the best use of them. This can be accomplished by doubling the capacity of freight cars, making the limit 300,000 pounds per car with six wheel trucks. The gross weight of such cars loaded would not be as much as the new Mallet locomotives that are being very generally adopted.

Limit of Economies Through Larger Cars.

During the last twenty years, the maximum freight car capacity has increased only 100 per cent., while the locomotive capacity during the same period has increased 400 per cent. The wide difference between the increase in the capacity of the locomotives as compared with the carrying capacity of the freight cars has necessitated the very long freight trains in order to give the heavy locomotives an economical load. This has resulted in an enormous increase in the maintenance of the small freight cars.

The question will naturally be raised as to why the railroads do not adopt a very much more substantial car of 150 tons capacity. The answer can be found in the records of all railroads in this country, which show that during the last ten years over 60 per cent. of the increased capacity of the freight cars has been unused in practise, while the extra cost of hauling the greater dead weight and the extra cost of maintenance has been incurred.

The fact is that everybody is complaining. Engineering experts who study these questions, as well as the railroad executives and operating officers, are surprised and disap-

pointed because big engines and big cars have apparently failed to accomplish expected economies. Shippers whose business has been disturbed by periodical increases in minimum weight requirements are disposed to complain because the railroads disregard commercial conditions, which demand the small carload unit; while the railroad traffic managers, pressed on one side by their operating and executive officers to get bigger loads for the bigger cars, and on the other hand meeting the protest of the shippers against further increase in the minimum weight conditions of the tariffs, are discouraged and almost desperate.

The demand for a small carload unit would not enter into the shipment of such commodities as coal, coke, iron ore, grain, building material and other commodities which are sold and handled in large quantities, under conditions which would make the shipper indifferent as to whether they moved in carloads of 20 or 100 tons, assuming the cost of loading and unloading to be the same.

The attitude of the shippers toward the big carload does not depend entirely upon the capacity or the cost of loading or unloading, but rather upon the way in which it is bought and sold—whether sold by a man who has a large quantity to sell or bought by a man who wants a large or small quantity—the desire of the retail merchant to get the minimum carload of flour, because of the original investment, interest in insurance cost of carrying the stock, depreciation in quality, chance of falling market, and so on. The same thing is true of sugar, canned goods, beans, and everything in the list of goods handled by small jobbers or very large retailers. In fact, when you get outside of the limited list of very large jobbers, nearly every buyer wants the smallest quantity on which he can get the minimum delivered price. If the railroads expect such people to buy a large quantity and co-operate in the loading of cars to capacity, their freight tariffs must offer indemnity for the greater cost of handling such larger quantities; and to get complete co-operation on the part of shippers, the tariffs should offer some material inducement to trade in large quantities, thereby loading cars to capacity.

Should Not the "Wholesale" Principle Apply?

It would seem that any remedy must involve some practical application of the wholesale principle to the transportation business; and for the same reason that the price paid for most commodities is in inverse ratio to the amount purchased, the railroads should, within the limit of their maximum car capacity, give the lowest rate to the man who makes the largest shipment.

The freight tariffs of the European railways are based on the wholesale principle, all rates, generally speaking, being graduated according to the quantity shipped. The American railroads have made what seems to be the mistake of limiting their rates to two base units—the carload, which is anything more than 36,000 pounds or whatever may be the prescribed minimum weight, and the less-than-carload, which is anything under 36,000 pounds and within the limit of the money charge which would be made for the minimum carload shipment.

To have only the two units for rate-making, the carload lot and the less-than-carload lot, was not advisable even twenty-five years ago, when the minimum was 20,000 pounds and the carload rate was applied upon relatively small quantities. Under the present-day conditions, when the shipper is expected to furnish full loads for cars of 40 and 50 tons capacity and requested to load not less than 18 or 20 tons in order to get the carload rate, there is still less justification for the failure of the carriers to work out some graduated scale of rates, according to the weight of such consignments, or in some other way make freight tariffs which would permit the forwarding of any shipment, however large or small, at a rate which would bear some consistent relation to the cost of service.

Grain tariffs generally provide that the rates will apply only when cars are loaded to capacity. In other words, the minimum weight is the marked capacity of the car in case of corn, wheat, etc., while the minimum weight for oats or other bulky grain is based upon cubical capacity of cars used. Railroads are not building cars of capacity less than

80,000 pounds. Therefore a shipper could not get the car load rate, which we will say is 15 cents per 100 pounds, unless he forwarded 80,000 pounds, or is able to get a smaller car. But it is difficult to get cars of 60,000 or 70,000 pounds capacity and almost impossible to get cars of capacity less than 60,000 pounds.

Difficult to Arrange an Equitable Plan.

The question has been raised as to why the present method of rate-making is considered better than the European method, or if not better, why the European method is not to a greater or less extent observed in making American railroad tariffs. The average railroad traffic manager is usually obliged to say that any tariff which would fairly meet requirements of small carload shippers, and offer due encouragement to those who would load cars to capacity, would be altogether too complicated. And the same traffic manager is also likely to say that it is difficult, if not impossible, to change rules and practices which have obtained for long periods of time and on which business has been organized and built up. He will further say that the graduation of rates on carload shipments according to weight loaded, could not be made without loss of gross revenue, because the carload rates are now subject to minimum weights, which usually represent about 50 per cent. of the average car capacity, and any attempt to increase the rate on small carload shipments would meet the protest of shippers and the veto of state and federal authorities. It would be possible to encourage maximum loading only by offering rates considerably less than the present carload rates. And since the railroads are now able, in one way or another, to get a large proportion of their carload shipments on a capacity loading basis, any attempt to graduate the rates on a consistent basis would certainly result in a loss of revenue.

Some Illustrations of the Wholesale Principle.

Nevertheless, this principle has been to some extent recognized in railroad freight tariffs in this country. The

most numerous examples of such rate-making are found in tariffs of the so-called trans-continental roads. In the case of canned salmon and several commodities which are commonly carried eastbound, these roads make two rates. For example, the rate on canned salmon from Seattle to eastern common points is 85 cents, subject to minimum weight of 40,000 pounds, and 70 cents, subject to minimum weight of 60,000 pounds.

A similar differentiation of rates according to minimum weights has been made to some items in the westbound tariffs of the trans-continental roads with result that nearly all of the tonnage moves under the lower rate, subject to the higher weight, thus proving that shippers can and will accommodate themselves to increased minimum weight requirements if there is any incidental saving in the rate.

Except as the trainload unit may be employed, the carload unit is the only useful basis for estimating railroad transportation cost. When any attempt is made by the railroads to measure the net revenue arising from any traffic, they consider the earnings per car. If the load is 80,000 pounds, the revenue will be twice as much as it would be if the load was only 40,000 pounds. But who will say whether it costs more to transport the 80,000-pound load, and how much more?

Engineering experts have furnished various rules for determining the tractive resistance, or what is commonly called "the drawbar pull" of cars carrying different loads. With knowledge of conditions as to grades, curvature, wind resistance, and so on, these experts can estimate the weight resistance, wheel friction, and all other items to be considered in determining the relative cost of moving a car loaded with 20 tons of freight, and the cost of moving the same car loaded with 40 tons of freight, between two given points under the same conditions. But it has been impossible to state any rule or formula which may be commonly used with confidence. We know only in a very general way that the cost per ton of transporting freight in cars loaded to capacity is very much less than the cost per ton of carrying the same freight in cars half loaded.

An Illustration of Increased Car Efficiency

I hope you will pardon me for referring briefly to what extent the United States Steel Corporation has been instrumental in creating a car supply during the year 1912, by increasing the average carload from 69,200 to 72,400 pounds.

The average carload of outbound traffic for the years 1911 and 1912 for ten of its shipping companies shows the following result:

During the year 1912, the average carload was increased 1.6 tons per carload. This increase of only 3,200 pounds to the average carload on outbound shipments means that there were 76,105 fewer cars used to handle an equal tonnage as compared with the average carload of the year 1911.

Both the shippers and the railroads were benefitted to almost an immeasurable extent in the switching and weighing avoided, namely, the great saving in operating expenses, switching service on 76,105 cars, or 152,210 terminal movements, and the expense of handling this additional number of both empties and loads through the various classification and interchange yards of the railroads, from point of shipment to destination.

The same ten companies last year made a still further increase in the average carload of 1,000 pounds per car, effecting a saving on the outbound shipments for the year 1913 of 35,840 cars. To illustrate, one company saved 122 cars by loading only 100 pounds heavier per car during the year. The record of another company emphasizes the importance of heavier loading perhaps more than any other example, for with an increase of only 400 pounds per car on its traffic means that 15,836 fewer cars were required to move the same tonnage.

The average time consumed by a freight car has been estimated by railroad students at 15 days for each trip throughout the country generally. On this basis a freight car should make twenty round trips a year; so that the 76,105 fewer round-trip cars means an actual increase in the car supply of 3,805 cars, and is equivalent to the creation of a car shop with a capacity to build that number of cars annually.

Taking the basis of $2.25 as the average gross earnings of a freight car per day, and the movement for the average car as occupying 15 days, the earning power of each car would be $33.75 per trip. The additional equipment that would have been required to handle this traffic, 3,805 cars, and this number of cars actually saved, can be estimated in value to the railroads by the earning power, for they were in use in other lines of traffic. Based on the average earning power of $33.75 per car per trip, there resulted $2,568,375 increased freight earnings to the railroads without the expenditure of a dollar for additional equipment.

This actual saving may be figured in another way, namely, the value of 3,805 cars at about $925 per car, would amount to $3,500,000, which represents an investment that the railroads were not compelled to make.

This is an actual record of what has been done, and shows what really could be accomplished throughout the country. It gives some indication of what enormous sums of money could be saved in operating expenses, which is the right way to increase net earnings without increasing the freight bills to the public, or decreasing the payroll for the employee.

Figure this in any manner that you may, it will prove conclusively the money value of conserving the freight car equipment, not only when there is a car famine, but at all times; and any plan that will increase the average carload will do more for car efficiency than anything else.

The Meaning of This to Pittsburgh.

Consider what the shippers of the Pittsburgh District generally could accomplish in the way of creating a car supply by increasing the average load per car. Based on the total Pittsburgh District tonnage for the year 1912, an increase in the average carload on approximately the same basis as the record referred to, of, say, two tons per car, would have resulted in the same tonnage moving in 409,524 fewer cars.

While the Pittsburgh District tonnage is merely used for a basis of computation, there can be no question but that even a more remarkable showing could be made in

increasing the average carload throughout the country generally, if the railroads would bring this subject before the shipping public. Shippers and consignees will be convinced that it is to their best interest to go to additional expense, if necessary, both in loading and unloading heavier cars, when they are made to realize that it means increased car supply; for there is nothing that interferes more with the general business of the country than a shortage of cars.

The ten companies referred to, went to a great deal of extra expense in building up the heavier loads, for it required not only additional labor, but took more lumber for additional car stakes and braces. However, the expense involved can be considered a good investment, for the return was four-fold, as indicated by the items above mentioned.

A Specific Illustration.

While this record for loading is away ahead of the average throughout the country, there is still a great deal of room for improvement. Take, for instance, the record made last year at National Tube Co. dock, at Lorain, in shipments of iron ore, where the average carload for the year 1912 was 96,312 pounds per car, and for the year 1913 it was 107,520 pounds per car, an increase of 11,200 pounds per car. I hope you will pardon me for referring to this dock specifically, but in the year 1912 it occupied the eleventh place in the average carload of the fourteen ore shipping docks on the south shore of Lake Erie, and in 1913 it occupied first place.

If we had followed the 1912 practice of loading, it would have required 6,903 more cars to have moved the ore that was forwarded during the twelve months of last year. There was 2,230,981 tons shipped (the largest quantity ever forwarded over this dock), an increase of 18 per cent. in tonnage with an increase in equipment used of only 2 per cent.

A Suggestion to Railroads.

It seems to me that the traffic officials of the railroads have it in their power to improve the situation in a very

simple manner, by issuing graduated commodity rates based on increased carload minimum weights, i.e., commence on the present basis of rates with the present minimum weights and have a table of higher minimums with lower rates.

For instance, from Seattle to New York, the table of rates on lumber could be made as follows:

Minimum Weight.	*Rate.*
20,000 pounds	$1.25 per 100 pounds
30,000 pounds	.85 per 100 pounds
40,000 pounds	.75 per 100 pounds
60,000 pounds	.60 per 100 pounds
80,000 pounds	.50 per 100 pounds

The present freight rate on lumber from the Pacific Coast to New York is 75 cents per 100 pounds, with 25 or 30 minimum carload weights that are based upon the cubical capacity of the car. The same method could be used by establishing graduated rates in the opposite direction, westbound. Take, for instance, the iron and steel commodities that are produced in large quantities in the East and needed along the Pacific Coast.

Objections might be raised to the large number of carload minimum weights and various rates. To avoid this, the suggestion has been made by Henry S. Prichard to use, for instance, the same minimum weights and basis of rates that are in effect to-day, charging for the excess weight over the prescribed minimum carload weight, say, one-fifth of the tariff rate. Applied to the above example, under the Prichard method, $1.25 per 100 pounds would be charged for the minimum of 20,000 pounds, and 25 cents per 100 pounds for the excess over the minimum, and the total resulting revenue would be the same as in the graded table above.

A similar schedule of graduated rates could be established between any other points and upon any other class of traffic, and perhaps even better examples could be made with flour and grain rates that are in effect to-day.

TRANSCONTINENTAL TRANSPORTATION.

All will agree that the method of making all-rail rates to the Pacific Coast must be entirely changed if eastern manufacturers are to enjoy any share of the Pacific Coast trade. To see this clearly, it is only necessary to bear in mind the recent large reductions in import duties and ocean freights, and the near approach of the opening of the Panama Canal, which will, if present all-rail rates of freight are maintained, shortly deliver the entire business to British, German, and Belgian manufacturers. Very much of the business has already been delivered to them because of the causes named. But it seems to me that the railroads, by promptly adopting some such plan of making rates as I have illustrated, can hold the business for themselves and for American manufacturers and do so at a substantial direct profit. This will further have the beneficial effect of equalizing their traffic east and west.

Some people may reach the conclusion that this is a drive to lower freight rates. But if it does lower rates it spells increased net earnings for the railroads, because every buyer in the land would specify the very largest carload in every instance, hence heavy loads. The result would be an actual saving in freight costs to the shippers that would compensate them for building up the heavier loads, and, at the same time, result in a marked increase in net earnings to the railroads.

With a graduated schedule of rates to select from, the low minimum carload shipments would become the exception, and the small capacity cars would disappear entirely. There would be three of the present minimum carload shipments forwarded in one car.

To fully appreciate the value of this saving in equipment, consider the following items:

First. The more desirable traffic to the railroads means lower cost of transportation and naturally lower basis of freight rates.

Second. The saving in switching expenses, avoiding congestion in the freight yards and expediting the movement of cars, both for the shippers and the railroads.

Third. The value to the railroads in having an enormous increase in the car supply without the investment of any additional capital.

Fourth. The actual saving to the railroads, in dollars and cents, of the cost of a large number of cars, and the additional saving in operating and maintenance expenses, and the valuable track room in terminal yards. The heavier loading of cars will, in itself, really create increased terminals without the expenditure of a dollar by the railroads.

For months past we have all, I have no doubt, been watching with a great deal of interest the effort being made by the railroads generally to secure permission from the Interstate Commerce Commission to charge rates of freight that would give them sufficient revenue to operate their properties properly, and give the public the service that the public is entitled to, and demands. The strongest argument that has been made in opposition to the views of the railroads, has brought forward the fact, that the railroads could themselves largely increase their net earnings by the practise of various economies. And, while I am not here to argue the rate case pro and con, I know of nothing that has been advanced in the field of economics that would do more to stop the present waste of our transportation facilities, than some such basis of rate-making as enumerated above. There are untold values of railroad equipment to-day that are not being utilized to their capacity or greatest efficiency because we are bound by an antiquated system of rate-making.

Seriously, I believe that the members of the American Iron and Steel Institute can do a great deal toward greater car efficiency by taking up the campaign for heavier loading of cars that will naturally encourage the railroads to build cars of very much heavier capacity, and I ask your cooperation in this movement, which, viewed from the standpoint of transportation, commerce, economies or efficiency, seems to spell Progress.

TRANSPORTATION

DELOS W. COOKE

Vice-President and General Traffic Manager, Erie Railroad Company, New York.

If it may be assumed in my brief discussion of Mr. Townsend's admirable paper that I represent railroad transportation, the compliment he pays the importance of our industry is hereby acknowledged, and he may be assured of our keen appreciation of the great service he is rendering us in his earnest, persistent and intelligent advocacy of the heavier loading of cars. Furthermore, no greater satisfaction could be given me than to point out, as I shall undertake to do, the service he is incidentally rendering the great interest he represents by requiring on the part of the railroads a tremendous increase in the use of steel.

The movement toward cars of larger capacity undoubtedly originated in a desire to economize in transportation cost. Whether this was the desire of the prosperous line to increase its profits or was forced on the weaker lines, as a clever lawyer once said, "By the scourge of crass necessity," is of little consequence; it was sound business policy.

With it, however, came the building of heavier power. The old-style car with the wooden under-frame and weak draft gear connections passed out because it would not stand the strain of the hundred-car train. The car that took its place is of steel or steel frame construction. The most natural thing in the world was to increase its capacity since the structural strength was there of necessity.

ADAPTING CARS TO LOADS.

If the master minds of the earlier day who decided upon and built the large car were disappointed that the carload did not increase in proportion to the increased capacity, the truth may here be stated that when they built the large car they probably gave commercial conditions little or no con-

sideration. They knew that if they had the car so constructed that it could be hauled in the longest possible train, somebody would be very busy trying to find a load for it no matter what its capacity might be. This had to do chiefly with the box car, which probably sees the greatest variety of service, but encouraged by the co-operation of shippers we are now building cars of seventy tons capacity for the iron and steel trade without a block of wood in them. The railroads must carry everything from feathers to pig lead, and, as Mr. Townsend says, commercial conditions—and it might be added the character of the commerce—govern the load.

The car of large cubic capacity is of great service to the railroads in enabling them to increase the load of light and bulky articles, which the varied character of commerce compels them to transport. It is practically impossible to secure a rate that will compensate for the light load on such traffic, but large cars will do much toward helping the situation in cases like:

	Average Carload.
Automobiles	12,000 lbs.
Excelsior	20,000 lbs.
Hay, Straw, Canteloupes	22,000 lbs.
Rags and Waste Paper	23,000 lbs.
Sisal	24,000 lbs.
Agricultural Implements	33,000 lbs.
Apples	26,000 lbs.
Grapes, Cabbage, Tobacco	29,000 lbs.
Oranges	28,500 lbs.
Onions	30,000 lbs.

Progress is being made, however, in securing heavier loading. On one trunk line the average loading on brick is 70,180 pounds, where the average minimum is 40,000 pounds, and on the same line the average on wheat is

71,463 pounds, the average minimum being 60,000 pounds. The average load of iron and steel on another trunk line which handles most of that traffic is 60,000 pounds, showing that there is still room for improvement.

Some Difficulties in Carload Ratings.

If the carload unit were the universal basis of commercial transactions it might be less difficult, even in these times, to endorse Mr. Townsend's suggested basis of scaled rates for increased loading; but the fact that in all big business the carload unit has little to do with the basis of sale, makes it seem that the already unjustifiable spread between carload and less-than-carload ratings is as far in rate reduction as the railroads can be expected to go.

There can be no doubt of the soundness of Mr. Townsend's suggestion, that the scaled rate would induce heavier loading in many lines of traffic, but this is by no means free from danger, especially in the mixed carload. The Supreme Court has decided that a railroad has no right to question the ownership of the goods in the application of carload ratings. This is developing the so-called forwarder or scalper to an extent that is positively startling, and it must be in some way corrected. Recent instances show that these forwarders by consolidating less-than-carload shipments of miscellaneous merchandise into carloads, and thus securing the carload rate, have a margin of 45 cents per 100 pounds, New York to Chicago, to divide with their patrons, making the railroad losses in many instances, as compared with their less-carload rates to which they are entitled, over $100 per car. The loading secured by the forwarders is more than double the average merchandise loading of the trunk line railroads, and the scaled weight basis applied to this traffic would simply increase the profits of the scalper and diminish those of the railroad. In this situation we have the anomalous condition of the railroad being required by law to publish and maintain rates for certain quantities, while the scalper with no investment and absolutely no responsibility is able to make rates as much as 50 per cent. less than the railroad over

the same line and divide his profits with the shipper. This, too, under a decision of the Interstate Commerce Commission sustained by the Supreme Court.

General Conclusions.

The four items of value to the railroads which Mr. Townsend gives as resulting from the saving in equipment are convincing, except as to the first, in which it could not be wholly agreed a reduction in rates naturally followed a reduction in transportation cost.

In the steel business it has been said that there is a bottom but no top. The top on railroad rates is so securely fastened as to make it absolutely necessary to keep any margin of profit intact, if any such thing exists. The railroads cannot afford to reduce their rates even to secure heavier loading, and we must appeal to you to continue your good work in helping us in this direction if for no other reason than it is to your interest to do so.

It needs no argument following Mr. Townsend's paper to show that we *must* get the heavier load, and it is likewise true that the heavier car must be built for the heavier load. The great importance to the iron and steel industry of co-operation in this direction is almost too manifest to permit suggestion, but let it be said that every part of the heavier car, from axle to running-board, calls for an increased use of metal and that metal is steel. The heavy train and the big car call for the big locomotive. A line I know has just built one containing 853,000 pounds of steel, which is capable of hauling a train of loaded freight cars four and three-quarters miles long, *if the cars would stand it.* Bridges have been strengthened to the extent of 30 per cent. axle-load capacity in the past ten years, which means that most of them have been renewed with steel.

Heavier rails and fastenings call for steel, steel.

Have we not found in this, therefore, the ideal basis for co-operation between our great industries? You have only to do your part. We *must* do ours.

RECENT PROGRESS IN THE BUILDING OF LARGE STEAM TURBINES

FRANCIS HODGKINSON

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The author is gratified at the Institute's request for a paper on the development of the large steam turbine. Indeed, he feels that this paper which will treat of the Westinghouse turbine with which he has been identified, might well be followed by similar papers on other makes of turbines, thus laying before the engineers of the steel industry a somewhat intimate knowledge of their features of design—these papers to be perhaps followed later by discussions covering the application of steam turbines to various steel mill uses.

It is generally true that up to the present time, the economic advantages of the steam turbine in its various forms have not been fully employed by the steel companies. The large public utility companies, whose product is power, have been compelled to employ every possible resource to cheapen power production. In that field the turbine has naturally found its chief development. With the steel companies power has been but one of many problems, and perhaps a relatively insignificant one. In consequence they have not reached the efficiency of power plant operation that has been reached by our modern central station plants. However, the bearing which this subject has upon the cost of power production carries its own suggestion.

A historical review here of the development of steam turbines covering the period since their inception in this country would be neither proper nor interesting. However, some reference must be made to the early machines to show the lines along which improvements have been made. The author is desirous of referring to the matter, also, because of public statements which have been made, intended to

show that the last fourteen years have seen the steam turbine brought to its present state of development from a very poor and uneconomical machine. This is by no means true as to the turbines about to be described. The earliest ones compare not very unfavorably with what can be done to-day with similar speeds and capacities. Unquestionably, improvements have been made in producing less expensive and more reliable detail design. Improvements in economy, however, have been due to increased speeds for a given capacity rather than to any material change of thought or principle as regards turbine systems. Very material advances have been made in the development of the high speed alternating current generator which have permitted turbines to be designed more appropriately for the volumes of steam involved. To-day, 5,000 K.W. 60 cycle machines have been built operating at 3,600 R.P.M., while in 1900, electrical engineers looked askance at such speed even for 500 K.W. units, and regarded 1,800 R.P.M. as a more desirable speed for this capacity and frequency.

The principal field for the steam turbines has been driving alternating current generators; and as there are, broadly speaking, but two frequencies in conventional use in this country—25 and 60 cycles—the speeds available are limited. Because of the difficulties of electrical transmission, there has not been much demand for direct current generators of large size. Further, because of the difficulty of designing direct current generators for high speeds, the number of direct current turbine installations is comparatively small. In the installations made of direct-connected turbines and direct-current generators, the speeds selected have been too high for successful operation of the generators and too low for the economical operation of the turbines. Within the last two years, however, reduction gears have been developed which remove this objection; so that to-day first-class designs of direct current generators may be driven by turbines as successfully as alternating current units. A number of such geared outfits have been installed giving entire satisfaction, the speeds being as follows:

Capacity K.W.	Turbine Speed R.P.M.	Generator Speed R.P.M.
150	6,000	900
300	3,600	900
500	3,600	720
1,000	3,600	514
1,500	3,600	360
3,750	1,800	180

The generator speeds given above are standard for motor-generator sets. The last unit named is about the largest size of direct current generator that has been built.

The First Turbine Installations.

The first turbine installation of any importance in this country was made in 1899 at the works of the Westinghouse Air Brake Company. The units were 400 K.W. capacity. About 70 machines of this design were subsequently built. A number of these units were tested and the following may be taken as typical of the results, operating with 150 pounds pressure, 100° superheat, 28-inch vacuum and 3,600 R.P.M.

Load in B.H.P.	Pounds Steam per B.H.P. Hour
264	14.48
445	12.87
593	12.05
759	12.06

In 1900, a machine of 2,000 K.W. capacity, operating at 1,200 R.P.M., was built. This excited considerable comment, particularly in Europe, because at that time it was the largest machine constructed with only a single cylinder. It was regarded by European engineers as a big undertaking and they expected that such a machine would be subject to severe distortions due to its great size and the large range of temperature involved within the single structure. It happened that at that time, machines were being built in Europe of 1,000 K.W. capacity in which two separate turbine cylinders were employed. These were coupled tandem fashion, the steam passing serially through them.

Greater security was no doubt assured by the two cylinder arrangement, since the two structures were so much smaller, and also, because of the smaller temperature range involved in each. It is interesting to note that our experience with the large single cylinder machines led us to copy foreign practice in constructing machines with two cylinders for large capacities, while they in turn were encouraged to build larger machines of single cylinder construction.

Two Cylinder Turbines.

In 1903, about sixteen two-cylinder machines were built by the Westinghouse Machine Company, ranging in capacity from 1,000 to 2,000 K.W., from 1,200 to 1,800 R.P.M., all of which gave excellent results from every standpoint. One reason that led us particularly to the two-cylinder design was the fact that at that time, reheating receivers were very fashionable among builders of reciprocating engines, and while we did not think reheaters were of particular value in connection with reciprocators, we did expect a substantial gain due to the reduction of moisture content in the steam passing through the low pressure elements. Careful tests showed that the gain in economy was slight when the live steam used for reheating was charged up against the machine and that the gain in economy did not warrant the increased investment. Results of typical tests on these machines operating with 150 pounds pressure, 75° superheat, 28-inch vacuum and at 1,200 R.P.M., are given below:

K.W. Load	Pounds per K.W. Hour
198.4	31.76
333.15	25.39
977.14	18.59
1,274.20	17.66

These two cylinder machines are of interest because at the present time there is a reversion to this construction for large machines. This system was employed by Mr. Parsons for the 20,000 K.W. machines lately furnished the

Commonwealth-Edison Company, of Chicago, and has also lately come to be used by other manufacturers in this country. The principal objection to the design is the great length, due to the increased number of bearings, etc., and the high cost.

Return to Single Cylinder Practice.

Further experience led to the abandonment of the two-cylinder design and the adoption of single cylinder machines for all sizes which were at that time built, which up to 1905 included machines of 7,500 K.W. capacity. At this time, there was little demand for 60 cycle units in large sizes, there being hardly any machines sold of over 2,000 K.W. capacity at this frequency. Conditions differ materially to-day; some of the largest machines now being sold are for 60 cycle service.

As already stated, turbines were limited in speed by the restrictions of the generators, and at this time (1905), the following may be regarded as the speed limits:

60-Cycle Service	R.P.M.
Up to and including 500 K.W. capacity........	3,600
Up to and including 1,000 K.W. capacity........	1,800
Up to and including 3,000 K.W. capacity........	1,200

25-Cycle Service	R.P.M.
Up to and including 3,000 K.W. capacity........	1,500
Up to and including 7,500 K.W. capacity........	750

All these machines were of the straight reaction design, the general character of which is shown in Fig. 1.

These machines were equipped with a regular fly-ball governor, controlling the turbine by means of a steam relay mechanism which admitted steam to the turbine in puffs. This system of control, while exceedingly sensitive and giving excellent regulation, has been found objectionable in some cases, particularly with the largest machines, on account of the interruptions to steam flow tending to cause reactions and vibration of the steam lines. The system, however, has this advantage, that the cylinder walls absorb heat from

the steam more quickly than they give it up. Consequently the temperature of the cylinder walls is higher than the average temperature of the steam, permitting an increased steam flow due to sudden increase of load to take place with less condensation. The continual motion of all valve and governor parts precluded any sticking, hence sensitive and close regulation was attained.

Normal and Maximum Rating.

These turbines were for the most part sold on what is known as the "normal rated" basis. The turbine carried a certain normal load, and the generator would usually carry that same load with a 40° rise. The generator would further carry continuously, 25 per cent. more load with a 50° rise, and 50 per cent. more load for a limited time—generally one hour—with a 60° rise. This is somewhat different from the practice of to-day when machines are sold at their maximum continuous rating or thereabouts. In these early days, the turbine was in competition with the reciprocating engine, and the turbine builder was called upon to do the things which the Corliss engine builder had been accustomed to do, namely, to have the point of best efficiency at some relatively low load, and means of carrying heavy overloads in excess of this. It is now customary to sell turbines on a basis of maximum rating. Unfortunately this leads to considerable confusion, as the maximum rating is no real indication of the actual size of the machine. As has been said by one writer, the business has begun to partake of "bargain counter methods." However, as different power plants have quite different requirements as to the relation between the point of best steam consumption and the maximum overload, it is not a matter which may be readily standardized.

So far as the generators are concerned, the modern system of giving them a maximum continuous rating at 50° rise with the possibility of carrying more load than this for a limited time, has much to commend it, but the matter is different with the turbine.

In a small railroad plant, the units being few and having to encounter certain daily peaks, it is convenient to have units capable of carrying overloads at some sacrifice of economy. Under such conditions, the turbines should have their most economical point at some fraction of the maximum load. Therefore, it follows that for small plants of this character, the conditions would best be met by the old system of rating. To rate such a machine at its maximum capacity is merely a difference in name, but different names cause confusion.

In the other type of power plant, that of a large public service company, with many machines of large size, where if a unit is running at all, it is operating at or near its maximum load, the most adaptable turbine is one which has its point of best steam consumption at from 80 to 85 per cent. of this maximum load—the generator having its maximum continuous rating at this same maximum load.

By 1909 very material progress had been made in the design of generators which reached the possible capacity of turbines arranged single flow, and with the customary blade speeds designed for 28-inch vacuum. It might be here noted that the low pressure blading limits the capacity of turbines. Considerations of centrifugal force fix the diameter of the last disc or drum. With this at a given diameter, there is a limiting dimension of blade which may be employed. A blade whose height is 15 per cent. or at most 20 per cent. of the diameter of the drum is not exceeded. To do so involves losses due to disparity of tip speed and root speed of the blades, there being no steam speeds to best satisfy the two extremes. With the given dimensions of blade passages, the weight of steam which may be passed depends on the desired limit of expansion—the vacuum to which the turbine is to expand and the desired velocity of steam, which latter should bear a definite ratio to the blade speed. In the case of a machine designed for high vacuum, and with blade speeds of 400 feet or more, it is customary for the steam velocity in the last row of blades to approach the critical point at full load—1,200 feet per second.

Double Flow Turbines.

While the limitation of turbine capacity at the low pressure end is that of providing area on account of the large number of expansions involved, the problem at the high-pressure end of the turbine is in dealing efficiently with the very minute volumes of steam there involved. It became evident, therefore, that if the low pressure were made double flow, permitting steam to flow through two low pressure elements in opposite directions, and the high pressure element were to remain single flow, increased capacity as well as higher economies would be obtained. Inasmuch as the number of elements in a turbine are proportional to the heat drop, it follows that a turbine made double flow will have twice as many elements as a corresponding single-flow machine. Therefore, when the low pressure portion was made double flow, in the manner above referred to, the machine became undesirably long, and to obviate this difficulty, the portion of the turbine corresponding to the small diameter shown in Fig. 1, was replaced with an im-

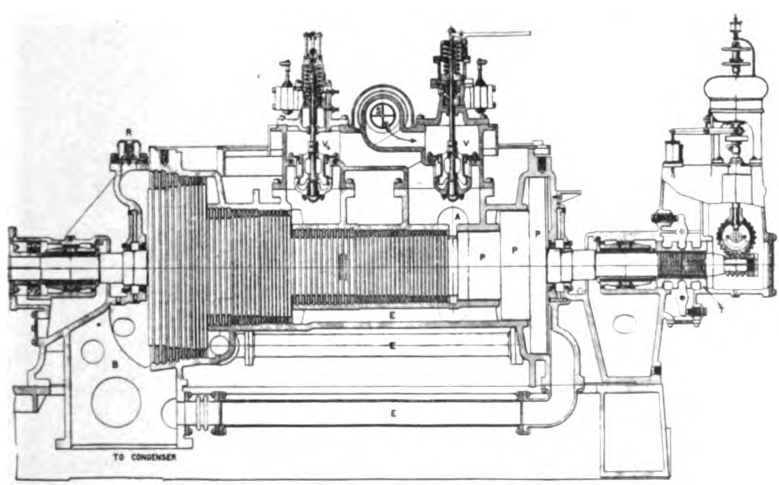


Fig. 1.

pulse element of the Curtis type. This has the advantage of dealing with a given heat drop with less axial length, as well as frequently being as efficient as a corresponding

reaction element in which, on account of the small steam volumes, the blades are small and the leakage ratio relatively high.

The impulse element of the high pressure has a further mechanical advantage of increased flexibility which permits the use of different nozzle areas and proportions, rendering it possible that a standard machine be readily changed to operate with different capacities, pressure and superheat. Inasmuch as a substantial pressure and temperature drop may take place in the nozzles, the employment of an impulse element permits steam of high pressure and temperature to be enclosed within small chambers separate from the cylinder structure. This machine called a "Semi-Double Flow," resolves itself into that shown in Fig. 2. A further increase of capacity may, of course, be obtained by running the low pressure blades at a higher speed and carrying the double flow principle to greater limits, i. e., only the impulse element being single flow, and all of the reaction elements, double flow.

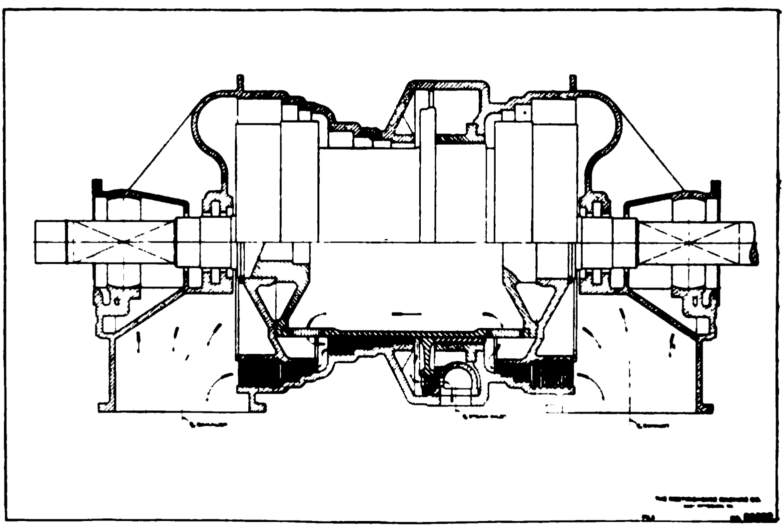


FIG. 2.

The employment of double flow turbines would not necessarily be advantageous were any rotational speed available. If a single flow turbine of given diameter, for

example, were made double flow, the blade passages would require to be of half the dimensions for the same capacity, thus doubling the leakage losses. Therefore, the double flow principle should be employed only where the volumes of steam are such that for mechanical or other reasons, sufficient areas of blade passage at the low pressure cannot be otherwise obtained. It should be remembered that if a speed be selected which is low enough to permit the low pressure blading being single flow, the speed would be far too low for the best design of the high pressure portion.

These limits of capacity, of course, apply to turbines designed for complete expansion in the blades in the case of reaction elements, or complete absorption of steam velocity in the case of impulse elements. By increasing the areas of the high pressure elements, an almost unlimited quantity of steam may be passed through the turbine, enabling it to develop correspondingly enormous horsepowers, but by so doing, either the expansion will not be complete within the turbine blading in the case of reaction turbines or in

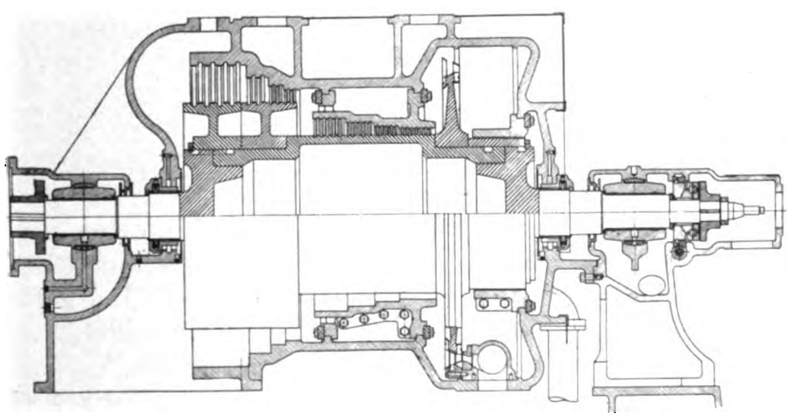


FIG. 3.

the case of pure impulse turbines, the velocity through the last row of blades will be so high with relation to the speed of the blades themselves that there would be losses due to residual velocity in the steam after it has left the turbine. The last row of blades is, therefore, the determining factor,

and the losses involved because of this being too small are precisely the same in any type of turbine.

The advantages of the impulse element for high pressure have been pointed out in the foregoing, and are equally applicable to single flow machines. Therefore, for the smaller capacity machines at the given speed, a single flow combination type machine as shown in Fig. 3 became a natural development.

The following table may be said to represent the limits of speed of standard turbines in 1900:

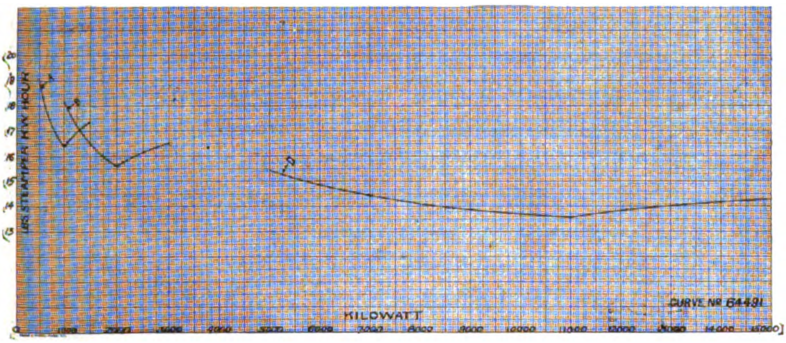
	60-Cycle Service	R.P.M.
A	1,000 Kw., single flow	3,600
B	Up to 2,000 Kw., double flow	3,600
C	Up to 6,000 Kw., semi-double flow	1,800
D	Up to and including 10,000 Kw., double flow	1,800

	25-Cycle Service	R.P.M.
E	Up to 3,000 Kw., single flow	1,500
F	Up to 7,500 Kw., semi-double flow	1,500
G	In 1909, some 10,000 Kw., 25-cycle machines were built of the semi-double flow type operating at	750

In all of the above, the capacities mentioned are normal ratings, the turbines being for the most part, capable of carrying 50 per cent. additional capacity. A certain number of tests on these machines are available, the results of which are shown in the curves, Fig. 4, the respective machines being identified by the letters given in the above table. All tests are reduced to a common operating condition of 175 pounds, 100° superheat and 28-inch vacuum. "H" is typical of the results obtained in tests on a 7,500 Kw. single flow reaction turbine operating at 750 R.P.M.

Up to this time, it was the general practice to design turbines for moderate vacua only. While purchasers of turbines talked glibly of 28-inch vacuum and better, it was indeed seldom that even 28-inch vacuum was actually maintained in the average plant. Of course, standardization is a factor of commercial success in machinery building, so

that it was desirable to design turbines for the average, rather than the exotic condition. The above-mentioned machines were not capable of expanding the steam materially beyond 28-inch vacuum at full load. Hence the vacuum correction, i. e., the gain in economy per inch of



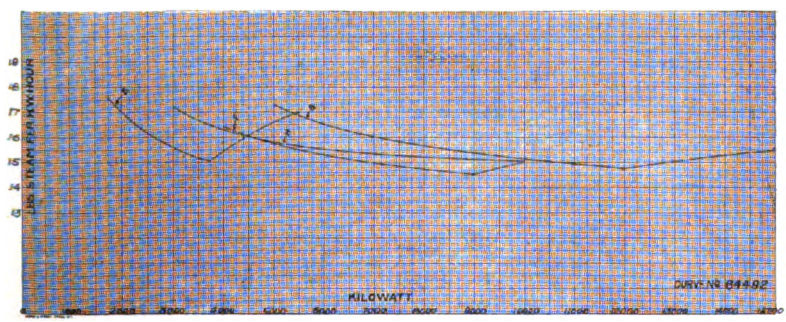


Fig. 4.

vacuum beyond 27 inches was relatively low, approximating 3.5 per cent. at full load. The rapid introduction of turbines up to this time brought with it very material developments in condenser design, making it desirable for large turbines, at least, to expand to 29-inch vacuum.

Losses in the Impulse Turbine.

Before describing the latest machines, some discussion as to the losses involved in the two respective types of turbine elements, viz., impulse and reaction, is in order. The impulse element comprises a nozzle in which the steam is

expanded to the exhaust pressure of that element. There is a complete energy transformation within the nozzle transforming the potential energy due to pressure into kinetic energy. This nozzle is followed by certain rows of blading. If the blades may be operated with about 40 per cent. of the velocity of the steam, one row will economically absorb this velocity and we have the well-known Rateau or De Laval type of turbine. If the blade velocity must be materially less than this, it is customary to employ more rows of blades, the steam leaving the first moving row being redirected by means of guide vanes onto a second row of moving blades. The highest efficiency obtained with this combination is where the blade velocity is about 22 per cent. of the steam velocity. With higher steam speeds and lower blade speeds, three rows of moving blades may be employed per element, in which case the highest efficiency will be obtained with this ratio about 13 per cent. The above is approximately correct with blade speeds of 300 to 500 feet per second. The highest efficiency, however, which may under favorable conditions reach 80 per cent., is obtained with a single row of blades. By using the higher pressure range in the nozzle or lower blade speed, or both, thus necessitating the greater number of velocity elements, the efficiency falls off quite rapidly, so that a three-row velocity stage element is now only used in very extreme cases, such as in the reversing elements of marine turbines. Their efficiency will hardly exceed 50 per cent. The efficiency of the two-row element may be 65 or 70 per cent.

The efficiency of the nozzle itself is of a high order, particularly with small pressure drops, approximating 95 per cent., for 8 to 10 B.T.U., falling off to about 82 per cent. for a 200 B.T.U. drop. The losses in the blades are:

(1) Hydraulic losses, which depend upon the relative velocities, blade angles, etc., and receive the same consideration as in a hydraulic turbine.

(2) Friction and eddies, which increase with the velocity of the steam in the blade passage, and hence become greater with a greater number of velocity abstractions.

(3) The nozzle zone does not generally occupy the com-

plete circumference of the circle. The blades on entering the zone of the nozzles, require that the medium that is stationary within the blade passage be accelerated by the steam leaving the nozzles which reduces the velocity. At either end of the nozzle zone, there are blade passages only partially filled, thus causing eddies, which condition is repeated at each velocity abstraction causing losses known as "spreading."

(4) At times, with the disc type turbines, skin friction on the exposed surface of the disc is considerable, owing to the large amounts of exposed surface. The blades themselves, where only a small portion of the circumference is occupied by nozzles, are an additional source of friction.

(5) Leakage losses in an impulse element are usually very small, and are at the point where the shaft passes through the diaphragms between the respective elements. In turbines herein described, as there is but one impulse element employed, no diaphragms are involved.

Losses in the Reaction Turbine.

In the reaction turbine, which it should be understood technically comprises a series of stationary and revolving nozzles and not blades, the following losses are involved:

(1) Hydraulic losses, which depend on the blade angles, and the ratio of the steam velocity to the blade velocity. This velocity ratio varies from 50 per cent. in the small to 75 per cent. in large units, the hydraulic losses for the above ratios being from 22 to 10 per cent. respectively.

(2) Nozzle losses—as in the case of the impulse turbine these are low. But particularly so in the case of the reaction turbine, because of the many stages and the small B.T.U. drop per stage.

(3) Leakage losses—in a reaction turbine, these form a most serious item, and where the steam volumes are small, such losses may amount to 20 per cent. But in the combination type turbines herein described, where reaction elements are employed for the low pressure portions, the losses become inconsiderable, ranging as low as 5 per cent.

(4) Skin friction, and the losses previously referred to

in the case of the impulse element under items 2, 3 and 4, are exceedingly low inasmuch as the whole of the annulus between the outer diameter of the drum and the cylinder wall is completely occupied with the flow of steam and it is not subjected to the disturbances at the ends of the groups of jets, as mentioned in the case of the impulse elements.

Radiation, bearing friction, etc., are relatively unimportant, and would be the same for either type of turbine element.

It is evident, therefore, that higher economy is to be obtained from reaction elements providing the speed of the turbine and the volumes of steam are appropriate for design with low leakage ratios, and conversely, the impulse element is better for the high pressure end of a turbine where the volumes of steam are small.

Turbine Blades.

Concerning the matter of turbine blading, there has been a good deal of misapprehension, although in earlier years there was considerable apprehension that was fairly justified. With all types of turbines, the design and material of turbine blading have undergone some evolution. Blading, of necessity, is subjected to very arduous conditions. It works in a steam current of considerable velocity, the steam oftentimes being laden with moisture, and sometimes with chemicals and solid foreign particles as a result of priming boilers. Centrifugal stresses must of course be properly considered but far more important is the fact that any design of blading in any design of turbine, must be able to withstand, so far as may be, the tendency to vibrate in the steam current. The characters of the two salient types of turbine elements, impulse and reaction, require quite different blading; the one, massive blade sections and the other, a relatively light section. However, the strain on the blades due to centrifugal force is the same in either case, and in the event of collision, between blades, the one is as subject to injury as the other with the difference, however, that the results of the wreck may be more far-reaching in the case of the more massive blades. In some of the early designs, breakages were